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IRRIGATION FROM RESERVOIRS IN WESTERN KANSAS AND OKLAHOMA

LETTER FROM

THE SECRETARY OF AGRICULTURE

TRANSMITTING,

PURSUANT TO LAW, A REPORT ON IRRIGATION FROM RESERVOIRS IN WESTERN KANSAS AND OKLAHOMA PREPARED UNDER SUPERVISION OF DR. SAMUEL FORTIER :: :: ::

January 21, 1913.—Referred to the Committee on Irrigation and ordered to be printed, with illustrations

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IRRIGATION FROM RESERVOIRS IN WESTERN KANSAS AND OKLAHOMA.

Introduction.

The agricultural appropriation act which provided for irrigation investigations for the fiscal year beginning July 1, 1912, contained the following provision:

> That the Secretary of Agriculture be, and he is hereby, authorized and directed to cause a thorough investigation to be made and report to Congress at the opening of the next session upon the feasibility and economy of irrigation by the reservoir system or plan in western Kansas and western Oklahoma.

The bill was not passed until August 10, 1912, and no additional appropriation was included above the amounts intended for the regular work of irrigation investigations. It was necessary, therefore, that the investigation be limited to the most western parts of these two States. The 18 western counties of Kansas and the 2 western counties of Oklahoma lying west of the line of 20 inches mean annual rainfall were covered. These are shown on the accompanying map (fig. 1). Even with this limitation in area but little more than a reconnoissance was possible.

A general reconnoissance was made, and five sites, two of them large and three small, were surveyed in Kansas. Other available reports were relied upon mainly for information regarding Oklahoma. The needs and advantages of irrigation were investigated and data were collected regarding the present development, mainly by pumping, in the portion of the Arkansas River Valley near Garden City.

General Description.

Agricultural settlement in Kansas began in the eastern portion of the State and has progressed westward, alternately advancing and retreating along the western limit of the area where farming under methods of the humid sections is successful. (Fig. 2.)

Kansas was organized as a Territory in 1854 and admitted as a State in 1861. The first wave of agricultural settlement in western Kansas occurred in the early seventies, during a succession of years of more than normal rainfall, although grazing had become important prior to that time. This period was followed by years of light rainfall, which compelled these first settlers to abandon their farms. A second series of wet years in the eighties caused a second wave of settlement which extended to the western border of the State and reached its height in 1887 and 1888. The normal rainfall of these two years did not check the faith in the country that had been in-

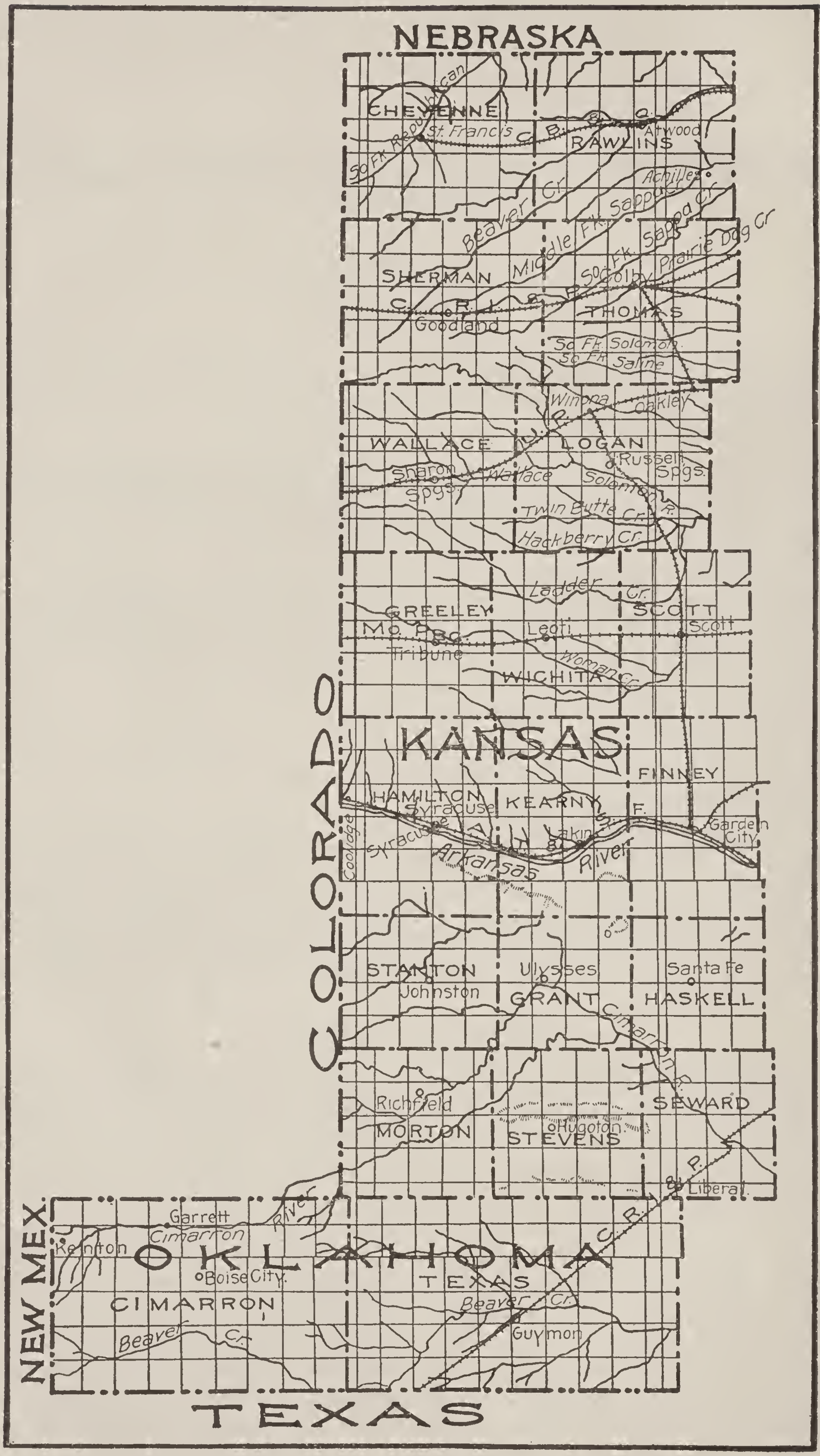

FIG. 1.—Portion of Kansas and Oklahoma included in this report.

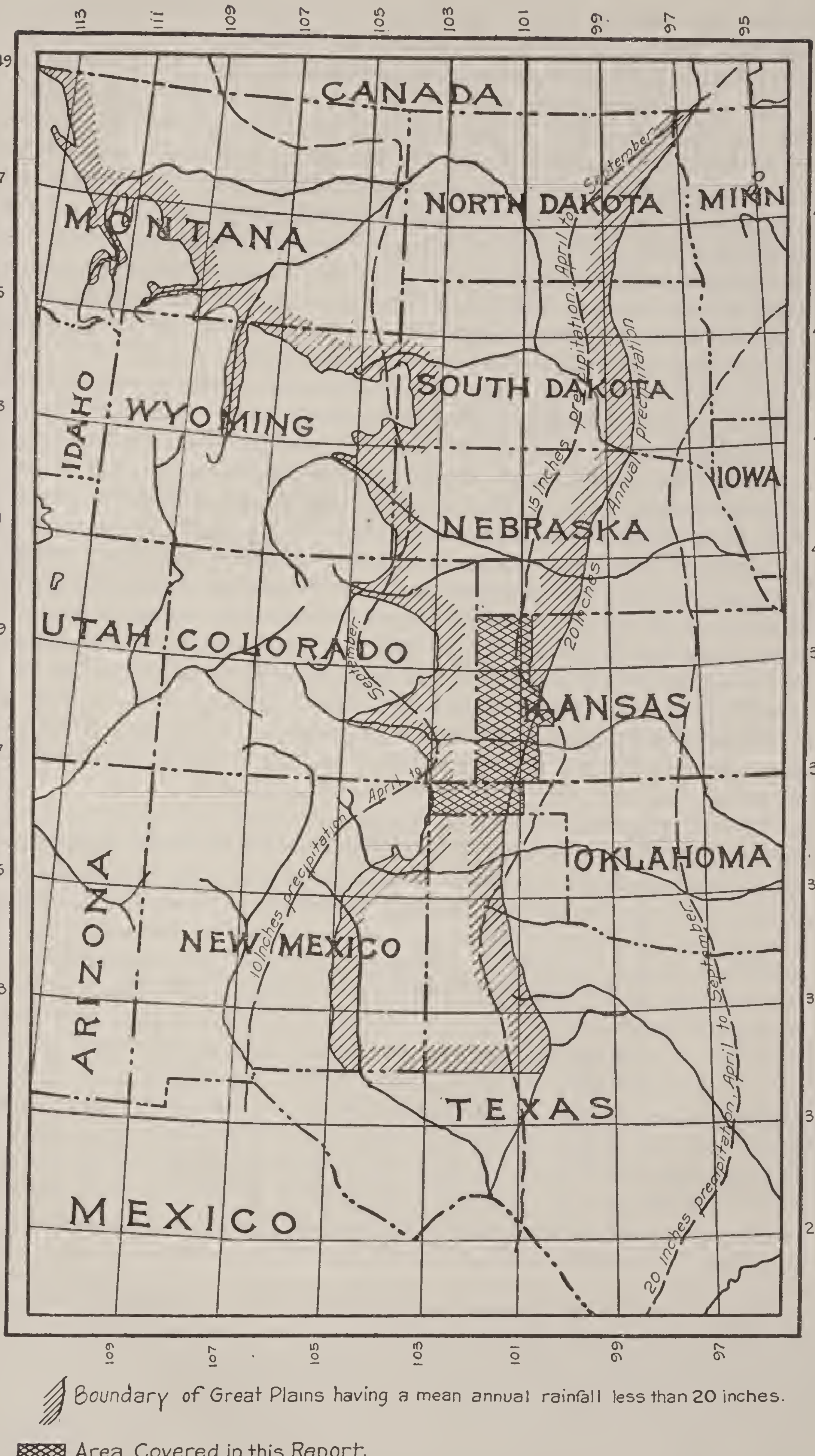

FIG. 2.—Great Plains area having less than 20 inches mean annual rainfall.
(Adapted from map page 11, Bul. 187, Bureau Plant Industry.)

spired by the high rainfall in 1883 and 1884. The succeeding unusually dry years, however, caused much hardship among the settlers however, and greatly reduced the population in this portion of the State, the population of the 18 western counties decreasing from 60,505 in 1888 to 28,127 in 1898, according to the State census. Since 1898 the population has increased steadily, being 56,950 in 1910. The population of the whole State has also varied, decreasing from 1,518,552 in 1888 to 1,334,734 in 1895 and increasing again to 1,690,949 in 1910. The present population in the 18 western counties has an average density of 1 person to 175 acres, or approximately 3.6 per square mile. Garden City, with a population of 3,714 in 1910, is the largest town. Goodland, Liberal, and Colby are the only others having a population of more than 1,000.

In the two counties, Texas and Cimarron, which constitute the extreme western portion of Oklahoma, the history of the development, while similar to that in western Kansas, has not been subject to such extremes. The population of the two counties in 1910 was 18,802, or 4¾ per square mile. The accompanying map (fig. 2) shows the relative sizes of the area covered in this report and the general Great Plains area, which has a mean annual rainfall of less than 20 inches.

The biennial reports of Kansas State Board of Agriculture furnish detailed annual crop statistics, from which the records for the 18 western counties from 1885 to 1910 were obtained. The acreage of prairie grasses is not included, as the classification of these and determination of the area is more indefinite than for the other crops. One million six hundred and eighty thousand acres of fenced prairie grasses were reported in 1910. The leading crop has varied during different periods, as shown in the following table:

Average acreage of principal crops in the 18 western counties of Kansas by 5-year periods.

Crop.	1885–1889		1890–1894		1895–1899		1900–1904		1904–1909	
	Acres.	Per cent of total.	Acres.	Per cent of total.	Acres.	Per cent of total.	Acres.	Per cent of total.	Acres.	Per cent of total.
Corn	139,400	63.8	117,400	17.7	165,900	25.1	121,600	19.0	182,000	16.9
Oats	15,400	7.1	42,900	6.5	31,000	4.7	10,600	1.6	25,900	2.4
Barley	300	0.1	30,100	4.5	50,300	7.6	54,900	8.6	161,000	14.9
Winter wheat	14,100	6.5	226,900	34.3	204,600	30.9	200,700	31.3	376,500	34.9
Spring wheat	6,800	3.1	131,100	19.7	93,100	14.0	52,100	8.1	86,700	8.1
Broom corn	5,200	2.4	36,100	5.5	19,100	2.9	14,600	2.3	23,600	2.2
Sorghum	37,300	17.0	53,900	8.2	51,000	7.7	126,100	19.7	112,900	10.5
Maize and Kafir corn	....	....	12,800	1.9	23,900	3.6	32,400	5.1	81,600	7.6
Alfalfa	....	....	11,400	1.7	23,200	3.5	27,200	4.3	26,400	2.5
Total	218,500	100.0	662,600	100.0	662,100	100.0	640,200	100.0	1,076,600	100.0

In the earlier settlement, from 1885 to 1889, nearly two-thirds of the total acreage was in corn, with only one-sixth in head grains and one-sixth in coarse forage crops. During the period from 1890 to 1894 winter wheat was the leading crop, with spring wheat second, corn averaging only slightly over one-sixth of the total. From 1895 to 1899 wheat continued to lead, corn increasing to one-fourth of the total acreage. In the last two five-year periods, winter wheat has continued to show the largest acreage, spring wheat dropping to 8 per cent of the total, and barley increasing from 8 per cent to 15 per

cent. Sorghum shows a decrease from 20 per cent during the period from 1900 to 1904 to 10.5 during the period from 1904 to 1909. The wheat is grown mainly in the northern counties, Thomas and Rawlins having over one-half the total acreage of winter wheat in 1910, and Cheyenne and Sherman two-thirds of the spring wheat. These 4 counties also contained one-half of the barley and oats and six-tenths of the corn in 1910. The largest average acreage of broom corn was raised in Stevens County, of sorghum in Scott and Logan Counties, and of maize and Kafir corn in Stevens and Seward Counties. Alfalfa is grown wherever the conditions are favorable, the largest acreage being found under irrigation along the Arkansas River in Hamilton, Kearny, and Finney Counties. During the period from 1904 to 1909, in the four northern counties, 71 per cent of the acreage was in head grains, 21 per cent in corn, and 8 per cent in coarse forage. In the three southern counties, during the same period, 32 per cent of the acreage was in head grains, 16 per cent in corn, and 52 per cent in course forage, including broom corn. This difference in the crops grown is representative of the different climatic conditions, the rainfall being somewhat higher and the evaporation slightly less in the northern counties. The area in the above crops amounted to 20.6 per cent of the total land area in the four northern counties and 5.9 per cent in the three southern counties. In Cimarron and Texas Counties, Okla., milo maize constituted 42 per cent of the acreage in principal crops, Kafir corn 12 per cent, sorghum 4 per cent, and broom corn 12 per cent in 1909, equal to a total of 70 per cent. Corn was grown on 6 per cent of the acreage and head grains on the remainder. But 11.5 per cent of the total area was planted to these principal crops.

Crop statistics for 1912 are not yet available, but it is probable that the sorghum, Kafir corn, and milo maize will show a larger proportion of the total acreage than in previous years both in western Kansas and in western Oklahoma. The present tendency of agricultural development is toward extensive combined farmimg and stock raising. This will allow the continued increase in the permanent settlement, although as dense a population as exists in the more eastern portion of the State can never be supported here. The coarse forage crops, sorghum, Kafir corn, and milo maize, adapt themselves to the varying moisture conditions and are of great value to this section.

In general, the advantages of irrigation are appreciated and its use is limited only by the difficulties and cost of securing the water supply. The growing of sugar beets has become an important industry in the Arkansas Valley, which is the only portion of the area where any general irrigation is now practiced. In raising staple crops in the western part of these two States the distances to large markets are not a material handicap, although the best opportunities come from the feeding of the local products and marketing of stock. In growing the small truck crops this district is handicapped in competing in the larger centers either to the east or west with the products of the lands adjoining these markets and such crops are mainly limited to local consumption.

There are six east-and-west railroad lines crossing the territory included in this report, which furnish adequate transportation to the main markets. The need of a north-and-south connecting line is felt, however. At present the only line of this character operates from

Garden City to Scott and Winona and from Oakley to Colby. The largest area without a railroad at present is the southwestern corner of Kansas. This is being remedied, however, by the construction of a line of the Atchison, Topeka & Santa Fe road from Dodge City, Kans., to Colmor, N. Mex. The local wagon roads, while largely unimproved, are generally in good condition for hauling.

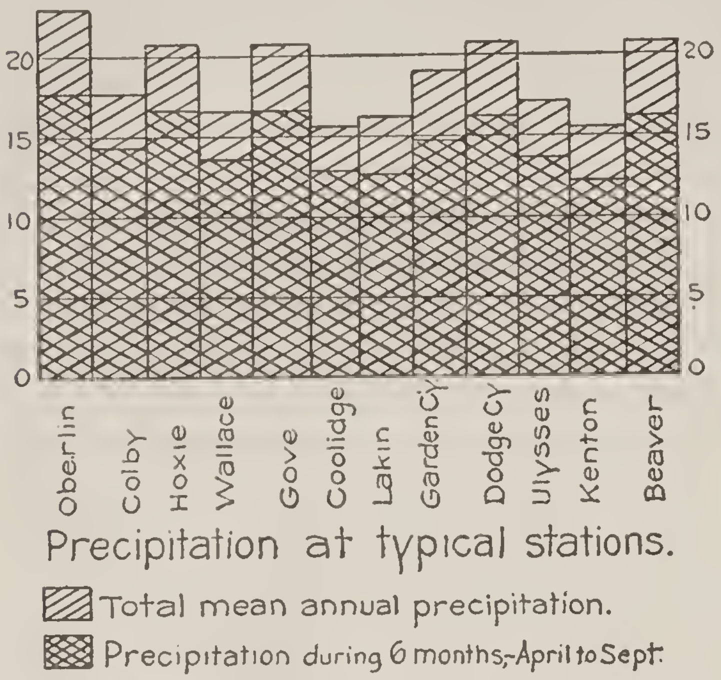

FIG. 3.—Mean annual precipitation and mean precipitation, April to September, at typical stations in western Kansas and Oklahoma.

A reconnoissance soil survey of western Kansas has been made by the United States Bureau of Soils.[1] Except along the streams or other broken areas the soils are quite generally classed as silt loams. Those north of the Arkansas River are considered as being derived from the loess, those south of this river from a Tertiary silt deposit known as plains marl. In southwestern Kansas the soils are more variable, sands, sandy loams, and silty clay loams being found. The short grasses are the natural vegetation. The soils are quite uniformly adapted to any crops which can be raised under the local conditions.

CLIMATE.

RAINFALL.

The rainfall in western Kansas and Oklahoma decreases at a fairly uniform rate from east to west. The accompanying table, compiled from the reports of the United States Weather Bureau, shows the longer available records. The annual precipitation at the stations named in the table is shown graphically in figure 3.

Mean monthly rainfall of western Kansas and Oklahoma.

Place.	Length of record.	January.	February.	March.	April.	May.	June.	July.
	Years.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Oberlin	25	0.41	0.86	1.37	3.02	3.17	3.28	3.62
Achilles	13	.26	.68	.85	2.38	2.52	3.03	3.41
Colby	24	.22	.54	.75	2.30	2.27	3.28	2.57
Hoxie	12	.36	.90	.84	2.46	3.04	2.70	3.00
Wallace	42	.24	.45	.52	1.82	2.63	2.50	3.34
Gove	23	.38	.69	.75	2.23	2.86	3.51	3.65
Tribune	12	.40	.52	1.14	2.54	1.68	2.63	2.50
Coolidge	14	.22	.44	.20	1.66	2.38	2.47	3.02
Lakin	22	.27	.82	.61	2.27	1.88	2.56	2.41
Garden City	23	.32	.82	.84	2.06	2.34	3.51	3.25
Dodge City	37	.47	.71	.88	1.87	3.34	3.32	3.38
Ulysses	21	.36	.67	.52	1.68	2.78	3.08	3.02
Hugoton	8	.53	.60	.77	2.87	1.46	3.64	3.65
Virogua	16	.45	.70	.67	1.80	2.18	2.44	3.47
Kenton	11	.25	.64	.63	1.78	2.48	1.91	2.23
Beaver	15	.60	.41	.70	2.19	3.53	3.19	2.77
Mean		.36	.65	.75	2.18	2.53	2.94	3.08

[1] U. S. Dept. Agr., Bur. Soils, Advance Sheets Field Operations of the Bureau of Soils, 1910.

Mean monthly rainfall of western Kansas and Oklahoma—Continued.

Place.	August.	September.	October.	November.	December.	Total.	April to September. Total.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Oberlin	2.89	1.80	1.24	0.63	0.61	22.90	17.78
Achilles	2.58	2.40	1.25	.54	.43	20.33	16.32
Colby	2.45	1.41	1.10	.51	.36	17.76	14.28
Hoxie	2.73	2.63	1.36	.39	.50	20.91	16.56
Wallace	1.97	1.32	.94	.47	.44	16.64	13.58
Gove	2.06	2.24	1.26	.59	.53	20.75	16.55
Tribune	1.65	.95	.72	.43	.38	15.54	11.95
Coolidge	1.91	1.39	.99	.54	.29	15.51	12.83
Lakin	1.92	1.60	.93	.52	.48	16.27	12.64
Garden City	1.79	1.78	1.08	.64	.62	19.05	14.73
Dodge City	2.59	1.77	1.40	.55	.56	20.84	16.27
Ulysses	1.42	1.79	.83	.51	.58	17.24	13.77
Hugoton	1.89	2.19	1.22	.78	.52	20.12	15.70
Virogua	1.77	2.15	1.15	.56	.66	18.00	13.81
Kenton	2.14	1.66	.82	.58	.34	15.46	12.20
Beaver	2.36	2.06	1.28	1.19	.58	20.86	16.10
Mean	2.13	1.82	1.10	.59	.49	18.62	14.68

While some of the stations lie east of the area included in this investigation, the general mean is fairly representative of the area investigated. The minimum annual rainfall is that at Kenton, 15.46 inches, and the maximum that at Oberlin, 22.90 inches. The accompanying small map (fig. 4) shows the variation in rainfall across Kansas. The portion falling during the crop season from April to September varies from a minimum of 12.20 inches at Kenton to a maximum of 17.78 inches at Oberlin, averaging 14.68 inches, or 79

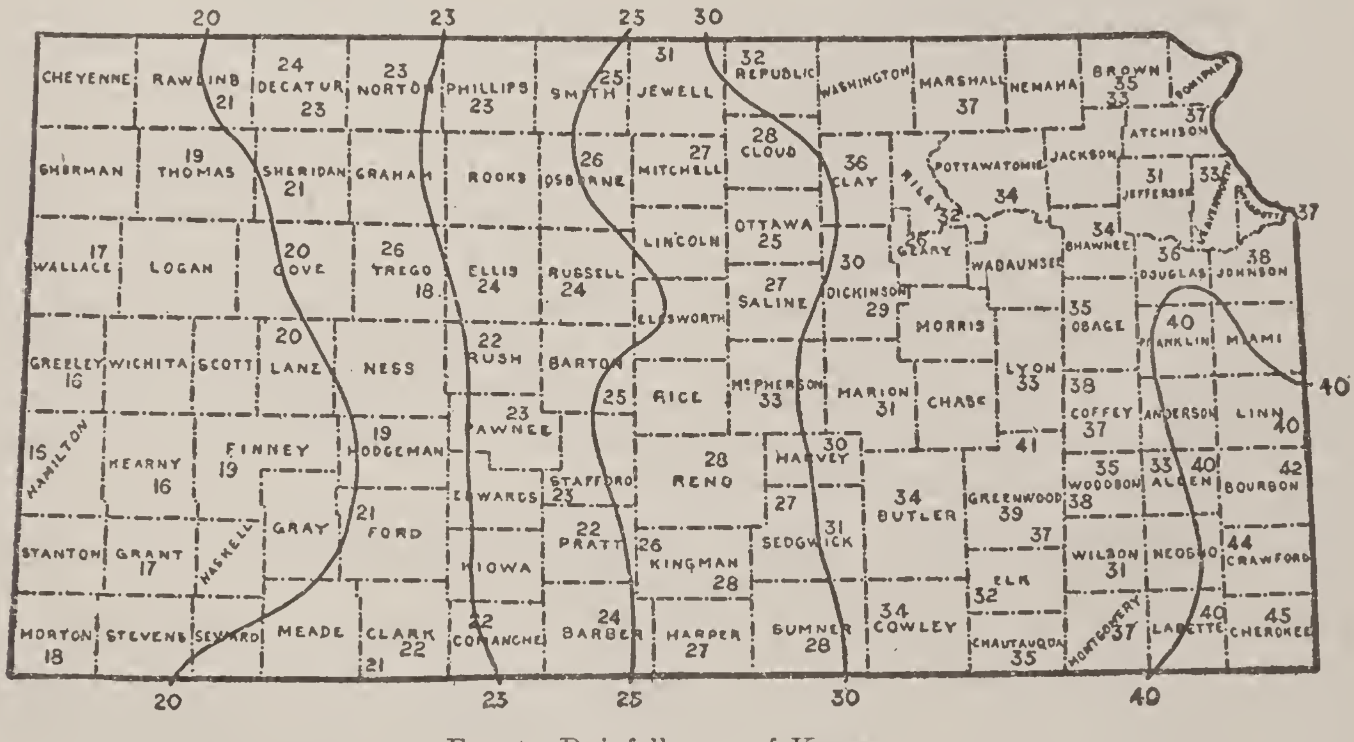

FIG. 4.—Rainfall map of Kansas.

per cent of the total mean annual rainfall of 18.62 inches. The amounts falling in each month are shown graphically in figure 5. This seasonable distribution of the rainfall is typical of the High Plains region and would be very advantageous for crops were it not for the fact that evaporation during the summer is also at a maximum. In the years of maximum rainfall the amount is approximately double the mean and in minimum years it is one-half of the mean. Three or four consecutive years may occur in which the

precipitation may be either higher or lower than normal and also two consecutive years have occurred in each of which the rainfall was only one-half of the mean, as at Colby, Wallace, and Gove in 1910 and 1911.

The evaporation from a free water surface at the Garden City experiment station for the past four years has averaged 52.7 inches for the six months April to September. The following table shows the summary of these records:

Evaporation from water surface at Garden City, Kans., 1909–1912.

Month.	1909	1910	1911	1912	Mean.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
April	6.35	7.76	7.10	6.80	7.00
May	8.99	6.33	9.72	10.82	8.96
June	8.76	9.43	11.85	8.58	9.66
July	9.97	10.48	10.25	10.64	10.34
August	9.88	7.61	10.18	9.15	9.20
September	7.46	6.82	8.92	7.09	7.57
Total	51.41	48.43	58.02	53.08	52.73

Records in 1910 and 1912 also indicate a mean evaporation of about 6 inches for October. Evaporation was measured daily, the maximum daily loss recorded being 0.78 inch, a loss of over 0.5 inch per day occurring in an average of 10 days each season. The effect of the hot winds in increasing the daily evaporation was quite noticeable.

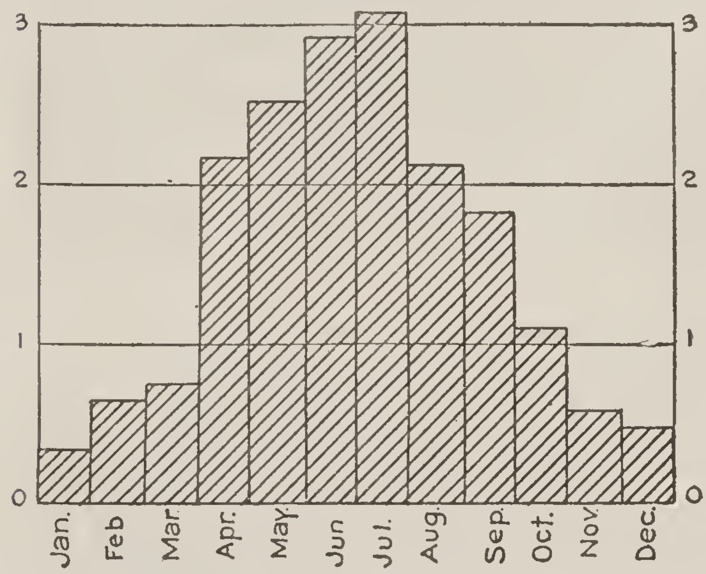

FIG. 5.—Mean monthly precipitation at stations in western Kansas and Oklahoma.

DROUGHTS.

The following table shows a summary of the droughts at the stations where the longest rainfall records are available. The daily precipitation records during the months April to September were examined, and periods of 30 days or over in which there was a total rainfall of less than 1 inch were considered as droughts which would be injurious to crop production and in which irrigation would be of direct advantage.

Periods of 30 days or over from April to September during which there was less than 1 inch of rainfall.

Station.	Length of record.	Number of droughts.	Average length.	Longest drought.	Number of years without droughts.
	Years.		*Days.*	*Days.*	
Oberlin	19	17	39	60	8
Colby	19	23	46	62	4
Wallace	26	44	46	82	0
Gore	19	29	44	79	3
Garden City	17	19	44	69	8
Dodge City	36	58	41	57	4
Ulysses	17	35	43	73	0
Kenton	11	25	44	85	0
Beaver	12	25	41	67	1
All stations	176	275	43	85	28

At all stations except Oberlin an average of more than one drought per season occurs, the mean for the full record being 1.56 droughts per year. In only 28, or one-sixth, of the total of the 176 years recorded were no droughts found, and at Wallace, Ulysses, and Kenton at least one such drought occurred in every year of record. The irregularity of the occurrence of these droughts is shown by a comparison of 9 years at Coolidge, Garden City, and Dodge City, lying in an east-and-west line across western Kansas. At Coolidge there were 18 droughts; at Garden City, 9; at Dodge City, the most easterly station, 14; the average length being 41 days. Crops which do not receive at least 1 inch of rain in 30 days under the climatic conditions which prevail in western Kansas and Oklahoma during the growing season will suffer, and the advantage of irrigation is evident. Even though the mean annual rainfall during the months of April to September is 14.68 inches, in this region of intense midday heat and almost incessant wind no method of tillage which may be employed can prevent a reduction in the yield of nonirrigated crops which may be subjected to such droughts.

As showers of one-third inch, or in some cases even one-half inch, during the season of high winds and evaporation can hardly be considered to be of much benefit to the crops, the size of the storms in which the greater portion of the total precipitation occurs becomes of importance. An examination of the daily rainfall records of the stations longest maintained in western Kansas and Oklahoma shows that practically one-half of the total precipitation occurs in storms totaling 1 inch or over. These heavy rains averaged $1\frac{3}{4}$ inches in depth. During the months April to September one of these storms occurs on an average of every 45 days; during the six months from October to March there is an average of less than 1 per year. It is these heavy rains which furnish the storm flows of the local torrential streams. Owing to the uncertainty of obtaining heavy rains during the winter season with which to fill reservoirs for use the next summer, storage would have to be obtained mainly during the growing season. This would shorten the length of time during which water would be held in the reservoirs and thus reduce evaporation losses. However, the climatic conditions on these local streams are the same as on the lands to be watered; in dry years, when irrigation is the most valuable, the supply available for storage would be the smallest. At Wallace during 13 years of the 27 examined, no heavy rains occurred from October to March, and in 6 years the total precipitation in storms greater than 1 inch was less than 5 inches. The maximum single storm occurred May 22, 1876, when 9.3 inches fell. Minimum run-off conditions occurred in 1911, when no rainfall exceeding 1 inch occurred from August, 1910, to June, 1911. The year 1911 was one of low rainfall, when storage would have been of much value, yet the precipitiation during the year was not sufficient to have filled reservoirs depending on storm run-off. These special details regarding rainfall at Wallace are typical of the other rainfall records. Records of excessive precipitation at Dodge City show that rates as high as 1 inch per hour are to be expected and that unusual storms will exceed this rate.

TEMPERATURE.

The mean annual temperature averages from 50° to 57° F., with a maximum monthly mean of approximately 75° in June and July and a minimum monthly mean of 29° in January. The extremes range from 110° to −30°. The last killing frost in spring occurs usually about May 1 and the first in the autumn from October 1 to October 10, giving a usual season between frosts of 150 to 165 days. Damage to standing crops in the fall is not usual although in some years delayed planting due to unfavorable moisture conditions in the spring may prevent some sorghum, Kafir, or maize from maturing before the autmun frosts.

WINDS.

The hot, dry winds which occur irregularly over this area are one of its greatest agricultural handicaps. One of these winds may in a day counteract the benefits of a preceding rain. In addition they make difficult the use of dust mulches, as the soil if broken too finely will blow and drift.

Conservation of Soil Moisture.

One of the most important factors influencing successful farming in the semiarid belt is the conservation of the moisture which enters the soil either from the natural precipitation or by irrigation.

There are three ways in which moisture escapes from the soil without benefiting the crops, namely, surface run-off, deep percolation, and evaporation. Under irrigation all three of these are more or less under the control of the farmer, but when only the natural rainfall is depended on, the lessening of evaporation losses is by far the most important since the other losses are only partly under the control of the farmer.

Water is drawn upward through the soil from one particle to another by capillary attraction and evaporated at or near the surface. If the soil is stirred by cultivation the soil particles are so completely separated that capillarity and evaporation are checked. This office has made a study of the effect of artificial soil mulches in checking evaporation. The following discussion and chart (fig. 6), taken from a report of these investigations,[1] give a summary of the results obtained at State College, N. Mex.; Bozeman, Mont.; Davis, Cal.; Reno, Nev.; Sunnyside, Wash.; and Caldwell, Idaho.

Tanks 23½ inches in diameter were used. An amount of water equivalent to a 6-inch irrigation was applied to 8 tanks at each of the 6 stations. As soon after irrigation as practical the surface of 4 of the tanks was stirred to a depth of 6 inches reproducing as nearly as possible the conditions of field cultivation. The difference in evaporation between the cultivated and uncultivated tanks was obtained by weighing at three or four day intervals.

The average total losses shown by the above data are 2.13 inches from the uncultivated and 1.58 inches from the cultivated soils, being 35.5 and 26.3 per cent, respectively, of the total 6 inches used in irrigation. Thus it is seen that cultivation reduced the loss more than 25.8 per cent. Fifty-one per cent of the loss from the

[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 248.

cultivated surface occurred in the first three days, that is, during the average period between irrigation and cultivation; while during the same period the uncultivated tanks lost 38.5 per cent of the total. The saving due to cultivation when figured in percentages is naturally low because of these heavy first losses. If the losses during the first three days in each case are disregarded, however, and only the losses after the first cultivation are considered, the saving due to cultivation averages 40 per cent of the loss from the uncultivated soil.

The most noteworthy feature of this experiment was the uniformly heavy losses immediately after irrigation. This emphasizes the necessity of early cultivation, especially in the heavier soils, where the percolation of moisture through the soil is slow and the moisture content of the surface soil is high. The actual saving of water may be small to the irrigator having an abundant water supply at hand, but it is well to remember that the saving of 0.5 to 1 inch of water per irrigation amounts to several inches during the season and often marks the dividing line between success and failure as regards the crop.

In figure 6 the solid lines represent the total loss in pounds from cultivated and uncultivated soils, and the dotted lines represent the same losses after the rainfall

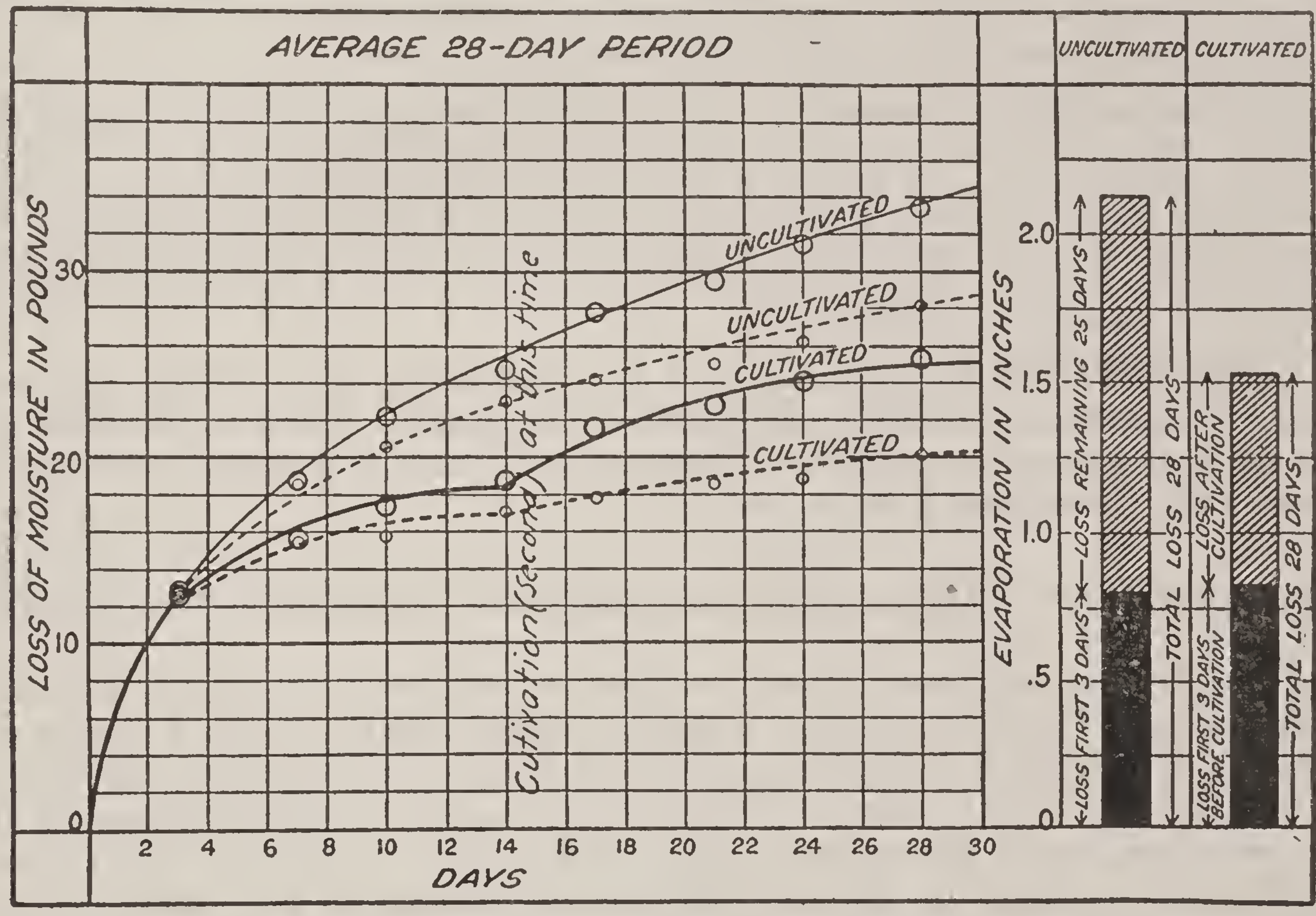

FIG. 6.—Average evaporation losses from cultivated and uncultivated tanks during first 28 days after irrigation. Average of losses at six stations.

(Solid lines show total loss including rainfall. Dotted lines show total loss excluding rainfall.)

for the different periods has been deducted. The irregularities in the solid curves are no doubt due to the evaporation of the rainfall, and when this has been deducted more uniform curves result.

Both curves of the cultivated soils show a decided break after the fourteenth day, due to the increased evaporation from the fresh soil turned up by cultivation at that time. After this small increase in loss the curves drop back and the losses for the remainder of the experiment appear smaller than ever.

These results show the saving of moisture due to cultivation, and while the conditions at none of the stations at which experiments were made are entirely comparable with those in western Kansas and Oklahoma, the general average should be closely indicative of the saving to be expected in any of the arid or semiarid States. The local difficulties in maintaining soil mulches due to the danger of having the surface blown away by the prevalent high winds cause

many of those practicing summer tillage to prefer to list their soil instead of using the usual mulch.

Agricultural conditions in this portion of the Great Plains area are quite thoroughly discussed in a bulletin of the Department of Agriculture.[1] In summing up the agricultural future of the region the author states:

> The hopes for better results in the future than have been secured in the past lie in (1) the continuance of high prices of agricultural products, (2) the general adoption of better methods of cultivation especially adapted to the conservation of moisture, (3) the introduction and development of more drought-resistant varieties of grains, forage crops, grasses, and vegetables, (4) the more careful and systematic management of the farm as a whole, (5) a change of attitude among the people from that of sojourners and speculators to that of permanent home builders, and (6) the fact that there is now a considerable population of drought-resistant settlers.

In discussing summer tillage it is estimated that not more than 40 to 60 per cent of the rainfall can be gotten deep enough into the soil of a summer-tilled field to be retained there.

> Ordinarily showers of one-third of an inch or less coming in the warm part of the year are utterly useless as far as storing water in summer-tilled land is concerned and not infrequently are a source of positive loss, as, being only sufficient to wet the surface mulch and cause a crust to form, they make cultivation necessary for no other purpose than to break the crust thus produced, in order to prevent the loss of water already stored in the lower layers of soil and to prevent the growth of weeds that would immediately spring up.

Summer tillage is not practiced as extensively in western Kansas and Oklahoma as in other dry farming sections. It is considered to be advantageous for winter wheat, but it is not generally thought profitable for spring grains or corn.

Comparison of Yields of Irrigated and Nonirrigated Crops.

Irrigation experiments were carried on at the Fort Hays Branch Experiment Station of the Kansas State Agricultural College in cooperation with this office in 1903 and 1904. The station is located at Hays, the county seat of Ellis County and about 150 miles east of the western line of the State. While this station is east of the portion of Kansas covered in this investigation, conditions are fairly representative of those throughout the western part of the State, where the value of irrigation is even greater.

The results of the experiments made in 1903 are given below.

Yield per acre of irrigated and nonirrigated potatoes.

Variety.	Width between rows.	Yield per acre.			Gain by irrigation.		
		Large.	Small.	Total.	Large.	Small.	Per cent.[2]
	Inches.	*Bushels*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	
Burbank, irrigated	36	62.92	41.25	105.17			
Burbank, nonirrigated	36	26.66	27.22	53.88	37.26	14.03	95
Kaw Valley Ohio, irrigated	36	39.83	37.22	77.05			
Kaw Valley Ohio, not irrigated	36	17.85	30.70	48.55	21.98	6.52	59
Kaw Valley Ohio, irrigated	30	49.51	32.63	82.16			
Kaw Valley Ohio, not irrigated	30	18.65	28.32	46.99	30.86	4.31	75

[1] U. S. Dept. Agr., Bur. Plant Indus. Bul. 215.

[2] Based on total yield.

In 1903 water was applied to cabbage twice and the effect of irrigation as compared with that not irrigated is shown in the following table:

Effect of irrigation on cabbage as compared with that not irrigated.

	"Sure head."	
	Irrigated.	Not irrigated.
Total plants	463	456
Number of good heads	195	94
Second-grade heads	141	111
Average weight per head, pounds	2.88	2.27
Plants not producing heads	120	251
Percentage of plants not producing heads	26.5	55.0

The following table shows the yield of corn irrigated, not irrigated, and gain resulting from irrigation:

Yield of varieties of irrigated and nonirrigated corn, and gain resulting from irrigation.

Variety.	Yield per acre.		Gain per acre due to irrigation.	
	Irrigated.	Not irrigated.		
	Bushels.	*Bushels.*	*Bushels.*	*Per cent.*
Smith Center Yellow	45.14	37.14	8	22
Minnesota No. 13	34.66	27.14	7.52	28
Colorado Yellow No. 1	23.52	20.47	3.05	15
Australian White No. 2	38.17	27.83	10.34	37
Colorado No. 3	35.94	27.83	8.11	29

Similar experiments in 1904 showed that all crops responded favorably to irrigation. The following table shows the comparative yields of potatoes for 1904:

Yield of potatoes.

BURBANK.

Acreage.	Season.	Irrigated.					Not irrigated.			Gain due to irrigation.			
		Date watered.	Water applied.	First grade.	Second grade.	Total.	First grade.	Second grade.	Total.	First grade.	Second grade.	Total.	Per cent.
			In.	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	
0.5	Winter..	Apr. 12-13	3.83	71.08	25.76	96.84	49.24	24.52	73.76	21.84	1.24	23.08	31.29
.5	Summer.	June 28	1.01	53.94	25.50	79.44	34.54	23.52	58.06	19.40	1.98	21.38	36.82

KAW VALLEY OHIO.

0.5	Winter..	Apr. 12-13	3.83	57.34	49.12	106.46	30.84	34.74	65.58	26.50	14.38	40.88	62.33
.5	Summer.	June 28	1.01	50.04	24.24	74.28	31.56	31.16	62.72	18.48	-6.92	11.56	18.43

Yields of Kafir corn and sorghum.

Acreage.	Season.	Irrigated.				Not irrigated; yield per acre.		Gain due to irrigation.			
		Date watered.	Water applied.	Yield per acre.		Seed.	Fodder.	Seed.		Fodder.	
				Seed.	Fodder.						
			In.	*Bu.*	*Tons.*	*Bu.*	*Tons.*	*Bu.*	*P. ct.*	*Tons.*	*P. ct.*
		KAFIR CORN.									
0.5	Winter..	Apr. 13-15.........	6.58	42.86	3.02	44.64	1.72	−1.78	−3.98	1.30	75.50
.5	Summer.	July 27............	4.02	35.36	4.50	19.64	1.72	15.72	80.04	2.78	161.60
		SORGHUM (COLMAN).									
0.5	Winter..	Apr. 15............	3.04	35.36	7.18	32.86	2.69	2.50	7.60	4.49	166.9
.5	Summer.	July 27............	5.54	40.00	7.53	35.70	2.69	4.30	12.04	4.84	179.9

Yield of corn (Kellogg's Pride of Saline).

Acreage.	Season.	Irrigated.						Not irrigated.	
		Date watered.	Water applied.	Yield per acre.				First grade.	Second grade.
				First grade.	Second grade.	Total seed.	Total fodder.		
			Inches.	*Bush.*	*Bush.*	*Bush.*	*Tons.*	*Bush.*	*Bush.*
0.5	Winter..	Apr. 15-16.................	5.38	46.28	5.14	51.42	1.71	41.58	5.70
.5	Summer.	July 26....................	4.54	53.42	5.72	59.14	1.77	37.42	5.70

Acreage.	Not irrigated.						Total gain due to irrigation.			
	Total.		Corn.		Fodder.		Corn.		Fodder.	
	Seed.	Fodder.	First grade.	Second grade.	First grade.	Second grade.				
	Bushels.	*Tons.*	*Bushels.*	*Bushels.*	*Tons.*	*Tons.*	*Bushels.*	*Per cent.*	*Tons.*	*Per cent.*
0.5	47.28	0.80	4.70	0.56	....	....	4.14	8.75	0.91	113.7
.5	43.12	.80	16	.02	....	....	16.02	37.15	.97	121.2

Yield of alfalfa.

Acreage.	Season.	Irrigated.			Not irrigated.		
		Date watered.	Water applied.	Yield per acre.	Yield per acre.	Gain due to irrigation.	
			Inches.	*Tons.*	*Tons.*	*Tons.*	*Per ct.*
1........	Winter....	Apr. 16-18..................................	16.9	3.40	2.60	0.80	30.74
1........	Summer..	July 27-29..................................	13.6	3.04	2.76	.28	10.14

Experiments carried on at the experiment farm at Garden City, Kans., in 1912, show the increased yield of crops due to the use of water. The yield of oats from irrigated plats was 55 bushels per acre and that from unirrigated tracts 30 bushels per acre, showing a gain of 83.3 per cent due to irrigation.

Twenty-four bushels of wheat per acre were obtained from irrigated plats and 13 bushels per acre from unirrigated plats, showing a gain of 84.6 per cent.

Water Supply.

INTRODUCTORY DISCUSSION.

The surface water supply of western Kansas and Oklahoma is comparatively small and the streams torrential in their flow. With the exception of the Arkansas River, they do not head in regions of sufficiently high altitude to have their summer flow maintained by melting snow but rise in the plains areas of eastern Colorado and New Mexico where both climatic and topographic conditions are unfavorable for a large run-off. The few actual discharge records which are available are presented in this report with the description of each stream. Most of the measurements, however, were made at points much to the east of the limits of this investigation and therefore show much larger discharges than are available in the western portion of Kansas and Oklahoma.

As the general climatic conditions on the drainage areas of the streams differ but slightly from those on the lands to be irrigated by them, in years of low rainfall when irrigation is most needed the stream discharges are at the lowest and the streams have their maximum discharge at the times when the demands for their use are the least urgent, because in years of high rainfall crops can be matured without irrigation.

It is unusually difficult to make any estimates of the run-off of unmeasured streams of this section on the basis of the drainage areas and the rainfall. The limits of the watersheds of the various streams are indefinite, the typical drainage areas consist of the steeper slopes near the creeks merging into the broad flat uplands on which no existing maps give contours sufficiently close to determine accurately the dividing lines between the streams. However, a close determination of the drainage areas would be of little use in such cases, as much of this higher upland is practically nonproductive of run-off owing to its general flatness and the numerous "lagoons," or slight depressions without outlets, which collect and retain the small run-off from a considerable proportion of the total area.

The short grasses form the typical vegetation, buffalo grass covering the larger areas. This grass sod prevents erosion almost entirely and yields but little run-off except in the heaviest rains. As the largest part of the annual rainfall occurs in the summer months when the evaporation is at its maximum, it is probable that practically all of the precipitation on the uncultivated uplands is returned into the air as evaporation. The principal drainage basins of which parts are included in this report are those of Republican, Smoky Hill, Arkansas, Cimarron, and Canadian Rivers.

REPUBLICAN RIVER DRAINAGE.

The Republican River unites at Junction, Kans., with the Smoky Hill to form the Kansas River, the drainage area of which lies intermediate between those of the Platte and the Arkansas Rivers. The tributaries of the Republican which are of interest in this investigation are the South Fork of Republican River, the two branches of Beaver Creek, North and South Forks of Sappa Creek, and Prairie Dog Creek, the last two of which rise in the area investigated but do not attain sufficient size to be of importance until after the more humid areas are reached.

The total drainage area of the Republican River is 25,800 square miles. The discharge for the period 1896 to 1905 was measured by the United States Geological Survey, from the records of which the following mean monthly discharge table is taken:

Mean monthly discharge of Republican River, near Junction, Kans., for the period July, 1895, to October 31, 1905.[1]

[Drainage area, 25,800 square miles.]

Month.	Discharge in second-feet.				Total in acre-feet.[2]
	Maximum.	Minimum.	Mean.	Per square mile.	
January	1,985	325	713	0.028	43,600
February	6,230	280	1,010	.039	55,800
March	13,500	504	1,500	.058	91,700
April	12,300	375	1,250	.048	74,000
May	47,520	325	2,830	.110	173,200
June	44,280	290	3,180	.123	188,300
July	37,500	75	3,000	.121	183,000
August	25,000	20	1,490	.051	91,000
September	10,500	20	704	.028	41,500
October	5,150	35	515	.021	31,500
November	1,480	63	469	.019	27,600
December	2,443	173	554	.022	33,600
The period	47,520	20	1,430	.056	1,034,800

[1] U. S. Geol. Survey, Water-Supply Paper 273, p. 231.

[2] Computed from mean discharge.

The mean annual run-off is at the average rate of 40 acre-feet per square mile of drainage area. The shorter records, given later, on the South Fork of the Republican, covering 5,900 square miles of the higher and more arid portion, indicate a mean annual run-off of from 6 to 8 acre-feet per square mile of drainage area. No records are available on the other tributaries in western Kansas, but it is to be expected that their run-off will be at a rate intermediate between that of the South Fork of Republican River and the average for the whole stream, as the highest rate and largest part of the discharge at Junction is derived from the eastern portion of the drainage area, where the rainfall is heaviest and the percentage of run-off highest.

SOUTH FORK OF REPUBLICAN RIVER.

The South Fork of Republican River rises in northeastern Colorado and flows across Cheyenne County in northwestern Kansas to its junction with the main Republican River at Benkelman, Nebr., the drainage area of the South Fork being approximately 6,000

square miles. Compared with those of the other streams of western Kansas, its watershed is rougher and the draws are steeper. Discharge records for parts of 1903 to 1906 at Benkelman, Nebr., are available and show a run-off of about 25,000 acre-feet during the 8 summer months in which the measurements were maintained. The South Fork flows throughout the winter and the total annual run-off may be from 1½ times to double that during the 8 months of record.

Estimated discharge of South Fork of Republican River at Benkelman, Nebr., 1903–1906.[1]

[Drainage area, 5,910 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.[2]
	Maximum.	Minimum.	Mean.	
1903.				
May 20 to 31	57	36	48	1,140
June	65	7	37	2,200
July	36	7	15	922
August	79	7	25	1,540
Sept. 1 to 5 and 14 to 30	22	7	15	655
October	50	7	39	2,400
Nov. 1 to 20	65	50	57	2,260
1904.				
March	102	31	60	3,690
April	66	6	21	1,260
May	255	47	92	5,680
June	397	47	132	7,850
July	115	5	39	2,420
August	89	11	24	1,480
September	47	5	13	774
October	115	31	57	3,540
November	66	47	59	3,530
1905.				
Mar. 17 to 31	249	96	159	4,730
April	300	52	141	8,390
May	137	52	100	6,150
June	283	21	68.6	4,082
July	152	5	35.4	2,180
Aug. 1 to 13	96	21	47.7	1,230
1906.				
April	317	73	129.0	7,680
May	215	52	99.3	6,110
June	52	....	90.3	5,370
July	183	....	10.9	670
August	....	....	....	....
September	....	....	....	....
October	61	....	21.8	1,340
November	61	36	48.0	2,860

[1] U. S. Geol. Survey, Water-Supply Paper 258, p. 106. [2] Computed from mean discharge.

Owing to the wide sandy channel of the river (Pl. I, fig. 1), water is obtainable throughout a large section of the bottoms, which vary from one-half to 2 miles in width, by pumping from the gravel, which averages about 15 feet in thickness and lies at low depths. Several ditches have been constructed to cover portions of this bottom land, 1,515 acres being reported by the census as irrigated in 1909. Only a part of the canals are operated at present.

Surveys were made by private parties for a reservoir having a dam in section 19, township 1 south, range 38 west, sixth principal meridian, filings being made in the office of the register of deeds at St. Francis. By the construction of a dam 70 feet high and 7,000 feet in length a

reservoir capacity of 69,000 acre-feet could be obtained. As the land which it was intended to irrigate lies in Nebraska, no examination of the site was made in this investigation. The portion of the river from the Colorado State line to points below St. Francis was examined, but at no place were any good dam sites found, the valley being broad and having no places where a dam could be constructed without excessive length in proportion to the storage and water supply available. Owing to the sandy nature of the river bottoms it would also be difficult to build a dam which would cut off the underflow.

Two small reservoir sites upon minor tributaries from the north, which are described later, were surveyed. Their use would not affect the larger problems of the utilization of the discharge of the South Fork of the Republican, which it is believed can best be accomplished by pumping on the bottom lands and by direct diversion, including winter irrigation, for the higher bottom lands and possibly some of the uplands.

BEAVER CREEK.

This Beaver Creek (there are several of its name in both Kansas and Oklahoma) rises in eastern Colorado and flows northeasterly into Nebraska, joining Sappa Creek a short distance above its mouth. No discharge records are available for this stream. The Middle Beaver unites with the main branch at Atwood, the total drainage area in Kansas being about 1,500 square miles. There is usually continuous flow from October to May in the section included in this investigation. Floods follow the heavier rains and contribute a large portion of the total run-off. The main valley varies in width from 1.2 to 2 miles, the bottom lands being used for alfalfa and other crops.

One reservoir site was surveyed on the main Beaver Creek in southwestern Rawlins County (p. 33). A few small lakes now exist along the creek, but they are not used for irrigation to any considerable extent. The site surveyed is the best that was found on this stream and was perhaps better than those found on any of the other streams included in this reconnoissance.

Good sites for medium-sized reservoirs would be difficult to secure, as the width of the valley makes the largest practical construction the most economical. Small ponds for portions of individual farms might be obtained, although good results are now secured by subirrigation on much of the bottom lands which such small storage would supply.

SAPPA CREEK.

Both forks of Sappa Creek, which joins the Republican River near Orleans, Nebr., rise in the area covered in this investigation and do not attain sufficient size to warrant any extensive use until the more humid sections are reached. The creek beds are eroded from 100 to 200 feet below the general level of the plains and follow valleys sloping about 15 feet per mile. The topography is somewhat more broken than on the creeks farther to the south, the side tributaries having cut themselves into the plain to a greater extent. No reservoir sites were surveyed in the Sappa Creek drainage, as no information regarding opportunities for storage could be obtained and none were noted in the portions of these creeks visited. However, the same opportunities for storage in small units exists on this stream as on the other creeks in this portion of the State.

FIG. 1.—CHANNEL OF SOUTH FORK OF REPUBLICAN RIVER, NEAR ST. FRANCIS, KANS.

FIG. 2.—BEAVER CREEK RESERVOIR SITE, LOOKING UPSTREAM FROM DAM SITE.

PRAIRIE DOG CREEK.

Prairie Dog Creek rises in the eastern portion of the area included in this investigation but does not attain sufficient size to be of value for irrigation before reaching the more humid sections. No examinations for storage were made on its drainage area.

SMOKY HILL RIVER DRAINAGE BASIN.

The second main drainage system encountered in going from north to south in western Kansas is that of the Smoky Hill River, which, with the Republican on the north, forms the Kansas or Kaw River at Junction City. The total drainage area is 20,500 square miles, of which about one-third drains through the Solomon River and one-sixth through the Saline River. Blackberry and Beaver or Ladder Creeks are other tributaries. In the western part of Kansas the topography of the Smoky Hill drainage is generally less broken than on the Republican River.

SMOKY HILL RIVER.

The main valley of the Smoky Hill River is deeply cut into the plain, and in some portions has the characteristic appearance of the bad lands. Records of the discharge of Smoky Hill River, near Ellsworth, from April, 1895, to December, 1904, a summary of which is given in the accompanying table, indicate a mean annual run-off of about 23 acre-feet per square mile.

Monthly discharge of Smoky Hill River near Ellsworth, Kans., for the period April, 1895, to December, 1904.[1]

[Drainage area 7,980 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.[2]
	Maximum.	Minimum.	Mean.	
January	172	14	45.6	2,800
February	213	17	57.2	3,100
March	1,410	14	36.5	2,200
April	1,834	10	93.5	5,500
May	11,392	13	321	19,700
June	4,856	10	410	24,300
July	7,947	5	448	27,500
August	862	5	256	15,700
September	7,840	12	170	10,100
October	1,390	14	477	29,300
November	187	8	423	25,100
December	268	12	347	21,300
The period	11,392	5	257.	186,600

[1] U. S. Geol. Survey, Water-Supply Paper 273, p. 215. [2] Computed from mean discharge.

The point of measurement is above the mouth of Saline and Solomon Rivers and over 100 miles east of the area included in this report. In its course through the varying geological formations the main river in its upper portion may be dry at some points and perennial at others. The larger part of the discharge at Ellsworth is derived from the lower drainage areas, both rainfall and run-off conditions being more favorable, so that the run-off from the western part of the drainage will be much less than the average for the whole area. A small flow is

maintained at some points in the upper course by springs derived from the lower-lying formations in which the river has eroded its channel. No favorable sites for reservoirs were found along Smoky Hill River itself, and no information regarding good opportunities could be obtained from those familiar with the stream. At the confluence of North and South Forks of the Smoky Hill, about 6 miles west of Russel Springs in Logan County, a dam could be constructed which would back water up both forks, and in this manner secure enough capacity to justify the cost of the long dam required, although it is doubtful if there is sufficient water supply available for such a reservoir. This site was not surveyed, because while it might be within the limits of practicability the depth of the creek below the flat uplands and length of canal required, the uncertain foundations, and other features which could not be investigated in the time available, were considered as being of such importance that the survey of capacity and dam site could not give conclusive results.

Ladder, or Beaver, Creek enters the Smoky Hill about 25 miles north of Scott, the total drainage area being between 1,200 and 1,500 square miles. A small reservoir site was surveyed near its mouth (see p. 43) which is typical of similar ones along its course. A gauging station was maintained during 1904 and 1905 above the mouth of Twin Butte Creek, and this shows a continuous flow in Ladder Creek, but sufficient discharge measurements were not made to establish a rating curve. The lower course is supplied by springs, so that at its mouth the flow is perennial. Twin Butte and Hackberry Creeks enter from the west and drain a rather rough area, the flow being torrential.

SALINE RIVER.

The Saline River rises in southwestern Thomas County and, like the Solomon, does not attain sufficient size before leaving the territory under consideration to warrant storage. Two discharge records are available, as shown in the following tables, which give records covering the run-off of the entire drainage area.

Mean monthly discharge of Saline River at Beverly, Kans., for the period April, 1895, to June, 1897.[1]

[Drainage area, 2,730 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.[2]
	Maximum.	Minimum.	Mean.	
January	108	17	50	3,100
February	243	27	62	3,400
March	67	27	47.4	2,900
April	693	20	126	7,500
May	3,000	14	166	10,200
June	16,000	21	1,020	60,600
July	10,000	73	430	26,400
August	493	41	104	6,400
September	92	9	48	2,800
October	6,130	6	144	8,800
November	188	9	54	3,200
December	98	13	47.6	2,900
The period	16,000	6	192	138,200

[1] U. S. Geol. Survey, Water-Supply Paper 273, p. 220. [2] Computed from mean discharge in second-feet.

Mean monthly discharge of Saline River, near Salina, Kans., for 1897 to 1903.[1]

[Drainage area, 3,311 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.[2]
	Maximum.	Minimum.	Mean.	
January	240	40	83	5,100
February	260	34	83.5	4,600
March	1,340	24	163	10,000
April	3,580	24	222	13,200
May	7,580	18	524	32,200
June	7,900	37	878	52,200
July	3,370	22	288	17,700
August	3,410	7	323	19,800
September	3,920	6	227	13,500
October	3,920	16	221	13,600
November	424	15	112	6,700
December	690	28	102	6,200
The period	7,900	6	269	194,800

[1] U. S. Geol. Survey, Water-Supply Paper 273, p. 220. [2] Computed from mean discharge in second-feet.

These show a mean annual run-off of from 50 to 60 acre-feet per square mile. The larger portion of the total discharge is derived from the eastern part of the drainage area. The run-off from the portion included in the territory covered by this investigation is only a small part of the average for the whole area.

SOLOMON RIVER.

The two forks of Solomon River rise in Thomas County and have not become of sufficient size before leaving the portion considered in this inquiry to require consideration, although it might be possible to find small storage sites. The upper drainage area consists largely of flat uplands, a considerable portion of which is composed of shallow "lagoons" without outlets, and the run-off as a whole will be small. The only available records of the discharge of either fork of Solomon River are those near Beloit from July 1, 1895, to June 30, 1897, and at Niles from May 1, 1897, to November 30, 1903, the mean monthly discharge as determined from these records being given in the accompanying tables. These records indicate the average annual run-off to be from 55 to 70 acre-feet per square mile of drainage area.

Mean monthly discharge of Solomon River, near Beloit, Kans., for the period July 1, 1895, to June 30, 1897, inclusive.[1]

[Drainage area 5,540 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.[2]
	Maximum.	Minimum.	Mean.	
January	1,160	5	109	6,700
February	3,055	19	148	8,200
March	1,160	8	161	9,900
April	18,500	8	1,160	69,100
May	4,700	72	290	17,800
June	8,740	104	1,110	66,100
July	21,800	108	1,720	106,000
August	24,000	92	992	61,000
September	960	14	143	8,500
October	6,760	7	165	10,100
November	1,120	7	245	14,600
December	930	7	103	6,300
The period	24,000	5	529	384,300

[1] U. S. Geol. Survey, Water-Supply Paper 273, p. 224. [2] Computed from mean discharge in second-feet.

Mean monthly discharge of Solomon River at Niles, Kans., for the period beginning May 1, 1897, ending Nov. 30, 1903.[1]

[Drainage area 6,820 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.[2]
	Maximum.	Minimum.	Mean.	
January	410	46	160	9,800
February	830	54	169	9,400
March	5,002	38	437	26,900
April	4,627	54	320	19,000
May	9,946	38	944	58,000
June	10,602	46	1,380	82,200
July	7,040	7	841	51,700
August	7,091	7	750	46,100
September	7,040	42	453	27,000
October	7,780	38	451	27,700
November	855	38	213	12,700
December	490	54	150	9,200
The period	10,602	7	522	379,700

[1] U. S. Geol. Survey, Water-Supply Paper 273, p. 224. [2] Computed from mean discharge in second-feet.

These records include the entire drainage area of the Solomon River, the run-off coming mainly from the eastern portion. The run-off from the portion of the drainage included in this investigation would be but a small part of the average for the whole stream. No reservoir sites were surveyed on the Solomon River, as no favorable opportunities for medium-sized storage were observed. Although it may be feasible to construct individual reservoirs, a water supply can hardly be considered available in this portion of the stream.

WHITE WOMAN CREEK.

White Woman Creek drains a strip of territory through Greeley, Wichita, and Scott Counties as well as some territory in eastern Colorado, amounting in all to approximately 1,000 square miles, any run-off reaching the lower portions sinking in the basin south and east of Scott. In the lower portions of its course its valley is from one-fourth to one-half mile in width, the bottoms rising in even slopes to the almost level and unbroken flat about 100 feet above, which forms a large part of the drainage area. While no records of run-off are available, there are but few signs of erosion along the streams. In the lower portion the banks have been raised by the deposits from overflows, giving the channel a canallike appearance. According to the recollections of those familiar with the creek, floods do not occur every year and there may even be consecutive years without discharge. It is probably possible to secure water by pumping from the underground supply which is augmented by the floods in White Woman Creek and thus utilize its flow. No favorable reservoir sites were seen. The dams required on sites inspected would have been long and the reservoirs shallow, giving a rather high cost per unit of capacity and a large evaporation loss. There is some land on which alfalfa has been able to grow by sending its roots to the underlying water. Pumping plants have recently been installed which obtain their supply with lifts of about 80 feet.

ARKANSAS RIVER.

The Arkansas River is the largest stream crossing the area included in this investigation and is the only one which rises in regions of sufficiently high altitude to have its flow maintained by melting snow. Owing, however, to the large areas of land in Colorado as well as in Kansas now irrigated from this river, both directly and by storage, and to the many uncertainties involved in the water rights which are now in the course of adjudication in the Federal courts, it was considered that any investigations which could have been made in the time available would necessarily be inconclusive regarding questions of water supply and that the survey of any reservoir sites which might have been found would have but little value. The Arkansas flows in a broad sandy valley which affords no opportunities for storage in its own channel owing to the length of the dam which would be required and the difficulty which would be experienced in securing a foundation. The United States Sugar & Land Co. has a reservoir, Lake McKinney, with a capacity of 30,000 acre-feet, which is situated on the side of the valley and filled through a canal. The Arkansas River receives practically no run-off from its drainage area in western Kansas, the rainfall either being lost by evaporation or sinking into the ground. On the south side sand hills parallel the river, 300,000 acres of which are included in the Garden City Forest Reserve.

The principal irrigation development in Kansas is found in the Arkansas Valley, water being obtained both by gravity diversion and by pumping, 90 per cent of the area irrigated in the State lying in Hamilton, Kearny, and Finney Counties. The benefits of irrigation have been fully demonstrated and its use is limited only by the uncertainty of obtaining river water. Among the later developments is the pumping of water for use on the uplands, lifts of 125 to 150 feet being required. A beet-sugar factory at Garden City supplies a market for this crop.

Stream records are available for various points on the Arkansas, but owing to the diversions made for irrigation these do not show the total run-off and give but little indication of the amounts now available for diversion.

CIMARRON RIVER.

The Cimarron River rises in the Raton Mountains in New Mexico and flows eastward along the Kansas-Oklahoma State line, which it crosses and recrosses. In the area covered by this examination it lies almost wholly in Kansas. The larger portion of its run-off is derived from its upper drainage area, the small rainfall on the portion in western Kansas yielding but little supply. The total drainage area above Arkalon, Kans., is 5,200 square miles. Only two short-time discharge records are available for the Cimarron River. One of these is for the station at Garrett, Okla., from May, 1905, to August, 1907; the other represents the station records at Arkalon from May, 1895, to October, 1896. The results of these measurements are given in the accompanying tables.

Monthly discharge of Cimarron River near Garrett, Okla., for 1905–1907.[1]

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1905.				
May 7 to 31	3,380	25	307	15,200
June	2,700	14	144.6	8,570
July	159	5	24.5	1,510
August	1,220	6	142	8,730
September	810	5	88.1	5,240
October	14	7	10.4	640
November	68	14	19.7	1,170
December	19	8	15.4	947
The period				42,000
1906.				
January	24	12	17.4	1,070
February	16	7.5	10.9	605
March	9	2.5	5	307
April	344	1.5	16	952
May	595	1.5	23.7	1,460
June	2,210	2.5	191	11,400
July	656	16	113	6,950
August	1,460	7.5	85.7	5,270
September	2,030	9	226	13,400
October	68	19	25.6	1,570
November	68	19	26.4	1,570
December	24	19	20.9	1,290
The year	2,210	1.5	63.5	45,800
1907.				
January	24	19	22.9	1,410
February	19	12	18.5	1,030
March	14	.5	4.15	255
April	105	.5	3.30	196
May	353	2.5	21.3	1,310
June	68	4.8	12.4	738
July	1,100	7.5	120	7,380
August 1 to 11	595	19	143	3,120
The period				15,400

[1] U. S. Geol. Survey, Water-Supply Papers 209, p. 38; 247, p. 63.

Estimated monthly discharge of Cimarron River at Arkalon, Kans.[1] *(9,200 square miles drainage area).*

Month.	Discharge in second-feet.			Total in acre-feet
	Maximum.	Minimum.	Mean.	
1895.				
May 14 to 31	22	18	18	648
June	170	19	47	2,797
July	659	14	149	9,162
August	170	16	30	1,845
September	19	16	17	1,012
October	18	16	17	1,045
November	18	17	17	1,012
December	18	17	17	1,045
1896.				
January	18	17	18	1,107
February	18	18	18	1,035
March	18	18	18	1,107
April	52	17	20	1,190
May	18	17	18	1,107
June	18	16	17	1,012
July	23	16	17	1,045
August	17	16	17	1,045
September	16	16	16	952
October	18	16	17	1,045

[1] U. S. Geol. Survey Ann. Rpt., 18 (1897), pt. 4, p. 244.

A comparison of the rainfall at Kenton, Okla., and Folsom, N. Mex., for the period of the stream record at Garrett indicates that the rainfall on the drainage area during this period was probably 20 per cent in excess of the mean precipitation. The annual run-off during the time of record was 42,300 acre-feet, which, on the basis of the comparative precipitation, indicates a probable mean annual run-off of about 35,000 acre-feet. As the run-off depends almost directly upon the heavier rains, it will vary as much as the rainfall and will be subject to the same wide fluctuations.

In 1895 and 1896, during the time that records of the discharge at Arkalon were maintained, the available rainfall records indicate that the year 1895 was about normal and that 1896 was almost a minimum year. By using the record July, 1895, to June, 1896, a total run-off of 22,724 acre-feet is given, which indicates that a mean annual run-off of 25,000 acre-feet is to be expected.

In its upper course the Cimarron River is subject to floods of very sudden rise and great intensity, which, however, subside quickly. In western Kansas the stream channel becomes wider and is sand choked. At some points the stream is perennial, while at others the normal flow sinks into the sands and only the torrential floods pass over the stream bed without being absorbed. Below Arkalon the flow of the river is usually perennial. But one reservoir site on the Cimarron was found in Kansas, this being described on page 36. At other points the valley is too wide, and sandy bottoms and lack of suitable building material are also unfavorable features of the locality.

In a report on the reconnoissance by the United States Reclamation Service on the Cimarron River the following statement is made:[1]

In southwestern Kansas and adjacent portions of southeastern Colorado suitable reservoir sites have not been found, and it is doubtful whether a more detailed examination is desirable. The Cimarron in Kansas flows over a sandy bed and has low banks with broad bottom lands on one or both sides; thus the opportunities for the construction of an economical dam are not offered.

In western Oklahoma quite thorough examinations for reservoir possibilities along the Cimarron were also made by the United States Reclamation Service without finding any sites where construction could be recommended. The sites at Garrett and at Kenton were considered the most favorable. With a dam 80 feet high and 1,800 feet long, a storage capacity of 58,200 acre-feet could be obtained at the Garrett site. Sixty miles of canal would be required to reach 30,000 acres, making the cost, including storage, too high for serious consideration.[2]

At the Kenton site a dam 60 feet high would have a storage capacity of 32,130 acre-feet. The drainage area above this site is 850 square miles, and the run-off is somewhat less than that shown by the records at Garrett.

A canal from the reservoir to irrigate land would be 30 miles in length, as the valley is narrow and contains only narrow strips on each side of the river. The cost per acre-foot of storage, not including the 30 miles of canal, would be $52.90.[3]

While the topographic conditions at the site of the forks in Grant County, Kans., are favorable, much uncertainty attaches to some of

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[1] Ann. Rpt. U. S. Reclamation Service, 2 (1903), p. 331.
[2] Ann. Rpt. U. S. Reclamation Service, 4 (1905), p. 300.
[3] Ann. Rpt. U. S. Reclamation Service, 3 (1904), p. 452.

the construction features, which are discussed in the description of this project (p. 37).

A project now dormant has been investigated by the Reclamation Service which involves the recovery of ground water from the stream bed for use as an additional supply for the present canals near Englewood, Kans., the main body of land lying in Oklahoma. This also is east of the area covered in this investigation.

BEAVER CREEK, OKLA.

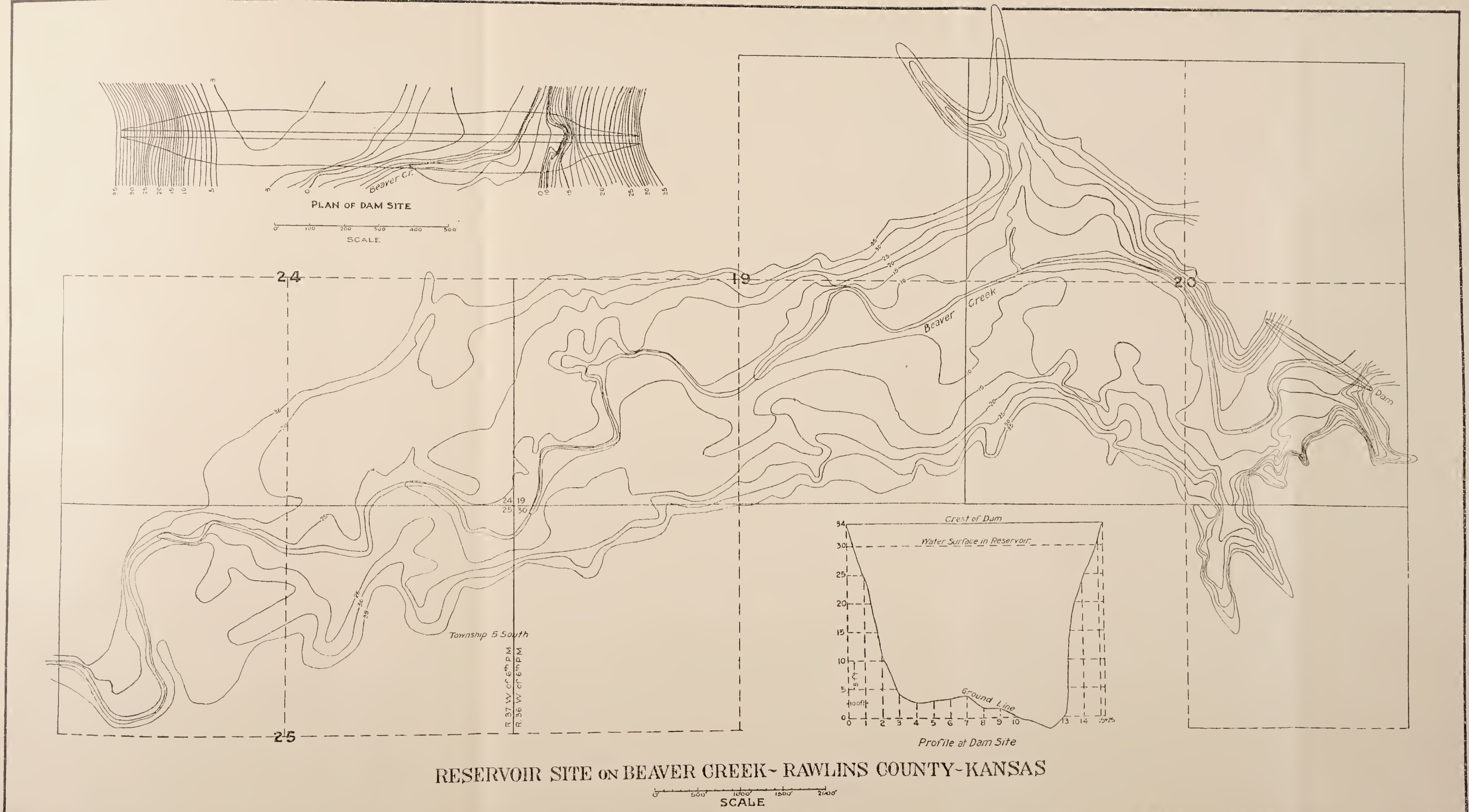
Beaver Creek, which unites with Wolf Creek in Harper County, Okla., to form the North Fork of Canadian River, traverses Cimarron, Texas, and Beaver Counties, which form the "strip" of western Oklahoma. Cimarron and Texas Counties are the only ones which were included in this investigation. Beaver Creek rises near Folsom, N. Mex., and receives much of its run-off from the upper portion of its drainage area. Throughout western Oklahoma the stream channel is wide and from 100 to 200 feet below the level of the plains and presents no good opportunities for storage. No run-off records are available, although gauge readings were maintained from March, 1904, to December 31, 1905, at Beaver, Okla., which show continuous flow. Records of the discharge of the North Fork of Canadian River near El Reno, which include the discharge of Beaver Creek, are shown in the accompanying table. The drainage area of Beaver Creek above the area covered in this inquiry is but a small part of the total at El Reno.

Mean monthly discharge of North Fork of Canadian River near El Reno, Okla., October, 1902, to April, 1908.[1]

Month.	Discharge in second-feet.			Total in acre-feet.[2]
	Maximum.	Minimum.	Mean.	
January	795	20	205	12,600
February	795	31	222	12,400
March	1,050	31	282	17,300
April	720	20	260	15,500
May	3,510	55	544	33,500
June	3,480	34	432	25,700
July	4,000	20	516	31,600
August	2,530	7	299	18,400
September	1,030	....	131	7,790
October	1,250	....	155	9,550
November	870	1	132	7,860
December	1,400	1	214	13,100
Mean	4,000	....	283	205,300

[1] U. S. Geol. Survey, Water-Supply Papers 131, 173, 209, and 247.
[2] Computed from mean discharge.

A thorough reconnoissance for reservoirs was made on this stream without success by the United States Reclamation Service. No further search for sites was made in the present investigation as the reconnoissances of the Reclamation Service are much more extensive and detailed than any that could be made within the time and funds available.



RESERVOIR SITE ON BEAVER CREEK~ RAWLINS COUNTY~KANSAS

The following quotation applies particularly to Beaver Creek:[1]

Generally speaking, in western Oklahoma, so far as known, there are no good opportunities for the storage of flood waters, natural dam sites being lacking. In addition, the water supply, with few exceptions, is unreliable. The great majority of the streams which it is proposed to utilize are dry during four or five months of the year and their freshets are exceedingly variable, both as regards the amount of water they discharge and the frequency with which they occur.

Reservoir Sites Surveyed.

RESERVOIR SITE ON BEAVER CREEK, RAWLINS COUNTY, KANS.

A survey was made of a reservoir site on Beaver Creek in the northwestern part of Kansas. The area covered by the proposed reservoir lies in sections 19, 20, 29, and 30, township 5 south, range 36 west, and sections 24 and 25, township 5 south, range 37 west, sixth principal meridian, in southwestern Rawlins County and a small part being included in southeastern Cheyenne County.

Beaver Creek rises in the eastern part of Colorado, flows northeasterly through Kansas, and discharges into the Republican River in Nebraska, having a total length of about 180 miles. The flow of the main creek is augmented by waters of the Middle Fork, the two branches having their confluence near Atwood, 34 miles below the proposed reservoir site. The valley lands of Beaver Creek vary from three-fourths of a mile to 2 or 3 miles in width and at the proposed dam site are 175 to 200 feet below the surrounding mesas (Pl. I, fig. 2). The drainage area of Beaver Creek consists of rolling mesas dissected by small ravines and, except along the creek bottoms, is treeless. The natural vegetation consists of buffalo grass, with some gramma grass and bluestem, forming a smooth, hard surface cover. The average slope of the drainage area in Kansas is about 20 feet per mile, which becomes a little steeper as the upper part of the drainage basin is approached in Colorado. No records of the flow of Beaver Creek are available, and, owing to the difference in character of the drainage areas, a comparison of the run-off can not be made with that of the Republican River in this vicinity or with other streams having similar conditions where records might be available. The creek generally flows from October to May and during the summer months may carry the run-off from heavy local rains. Any determination of the run-off of Beaver Creek is difficult to make since the percentage of the rainfall reaching the stream is hard to determine, and the extent of the drainage basin is estimated. A dam having the water line at the 30-foot contour would give a reservoir capacity of 10,115 acre-feet and one with the water line at the 35-foot contour would give a capacity of 14,685 acre-feet. A map of the reservoir site and a plan and profile of the dam site are shown in Plate II. If the stream proved sufficient for storing 10,000 acre-feet, no difficulties would be encountered in raising the dam so as to provide for storing larger amounts.

Estimates were made on an earth dam having a top width of 20 feet and side slopes of 2½ to 1 on the upstream side and 2 to 1 on the downstream side. The elevation of the crest of the dam is taken at

[1] Ann. Rpt. U. S. Reclamation Service, 3 (1904), p. 462.

the 34-foot contour, which provides 4 feet above the crest of the spillway. The length of the dam on top would be 1,525 feet and the total contents would be 124,500 cubic yards of earth. The capacity of the reservoir at various heights of dam is shown in the following table:

Capacity of Beaver Creek Reservoir site.

Contour.	Area.	Capacity of section.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
0	7.3	....	....
5	42.6	125	125
10	174.5	543	668
15	296.0	1,176	1,844
20	459.0	1,889	3,733
25	632.1	2,729	6,462
30	829.0	3,653	10,115
35	999.1	4,570	14,685

Another dam site a short distance upstream was surveyed. Estimates were made on this for the same height and side slopes, and while the yardage was slightly less the lower dam has the advantage of a greater reservoir capacity and receives the run-off from an additional small ravine. The greater part of the dam would rest on firm flat-bottom land now planted in alfalfa and should be suitable for the foundation of an earth dam when properly prepared. It was not possible to make any examination of the subsoil conditions with the time and means available for this investigation, but it is not probable any serious difficulties would be encountered in the construction. The soils on the land that would be submerged are classified by the Bureau of Soils,[1] as in the Lincoln series, the various types of which are undifferentiated but which in this section are generally heavy, alluvial silt, with but little sand in mixture and free from sand in the subsoil. For this reason there should be little seepage from this reservoir.

The north end of the dam would rest on a large hill on the other side of which a natural wasteway was formed by a saddle in the hills. It is not probable that the wasteway will be used to discharge any large amounts of water, although provision should be made for wasting flood flows for a short time. It should be safe to leave this natural wasteway in its original condition until it becomes evident that protective measures are needed, as the even slopes of buffalo sod will resist erosion for some time. Any flow wasting through the saddle will spread out over about 100 feet in width, and as at present there is no eroded channel on the lower side, there is little probability that any floods will come close enough together or be of sufficient duration to do great damage but that ample time in which to make any repairs to prevent cutting back into the reservoir will be available. The slope of the ground below the wasteway is such that any overflow will be carried into the creek about one-fourth mile below the dam. The south end of the dam would abut on a nearly vertical earth bluff which forms the valley wall at this point.

[1] Reconnoissance Soil Survey of Western Kansas, U. S. Dept. Agr., Bur. Soils, Advance Sheets—Field Operations of the Bureau of Soils, 1910, p. 83

These hills on either side would afford plenty of good material within easy hauling distance for building the dam. The construction of this dam would include stripping the surface for the base of the dam and the excavation of a cut-off trench to be refilled with selected material. Two cast-iron gates should be provided. It would be necessary to provide a paving or riprap on the upstream side. Outcroppings of rock were observed near the dam site and this rock might be used in the construction. A reservoir having the water line at the 30-foot contour would flood 829 acres, much of which is improved alfalfa land and valued at about $40 an acre, and in condemnation its cost might exceed this amount.

To reach the lands desired to be irrigated, which lie south and east of Atwood, would require a canal about 25 miles in length, which would follow along the valley bluff for some distance before reaching the mesa land. The irrigable lands have a uniform slope to the northeast of about 10 feet per mile. The soils in this section are classified by the Bureau of Soils as Colby silt loam, underlying the top of which is a clay subsoil. The land is now farmed principally in grain and is valued at about $20 an acre. Alfalfa would prove a valuable crop if water were obtained and should yield 4 or 5 tons per acre per season. The yield of milo maize, Kafir corn, and all crops would be increased with the use of water. The land would require but little preparation for irrigation, and after the sod is broken it is easy to cultivate.

On the basis of a duty of 2 acre-feet per acre measured in the reservoir sufficient water could be stored for the irrigation of about 5,000 acres of land. The cost per acre-foot of storage capacity is estimated at about $10.

Time and funds allotted to this inquiry did not permit a survey of the proposed canal line from the dam site to the irrigable lands, but it is estimated that the construction of the canal system would make the total cost of bringing water to the land in the neighborhood of $35 an acre. This, together with the initial cost of the land at $20 an acre, would mean an outlay of $55 an acre.

This project has been surveyed by private parties who spent considerable time and money in looking for a storage site, and it is probably as favorable a location as exists in the northwestern part of the State.

RESERVOIR SITE AT THE FORKS OF CIMARRON RIVER, GRANT COUNTY, KANS.

The largest site surveyed in this reconnoissance is situated on the Cimarron River, in the southeastern part of Grant County, about 35 miles northeast of Liberal, where a dam 30 feet high would cover 2,200 acres and store 23,800 acre-feet. The agricultural development of the lands in the vicinity of this reservoir has been retarded by the lack of adequate railroad facilities. This has been remedied by the construction of the Colmer cut-off of the Santa Fe Railroad, which passes within 2 miles of the dam site. The more drought-resistant forage crops and broom corn are now the ones principally grown, the total area cultivated being but a small proportion of the total agricultural land. No gauging station has been maintained at this point on the Cimarron, and owing to the peculiarities of this stream it is difficult to estimate the discharge at one point by comparison with

the discharges at others. As shown in the general discussion of water supply (see p. 31), the mean annual run-off at Garrett, Okla., 100 miles above this reservoir site, is probably about 35,000 acre-feet per year. The Cimarron at Garrett is practically perennial in its flow, the larger part of the discharge, however, occurring as floods. The mean annual discharge at Arkalon, Kans., about 25 miles below the site, as indicated by a record of 16 months in 1895–96, is probably about 25,000 acre-feet, of which about one-half consists of a quite uniform perennial flow and one-half of flood discharges. At the reservoir site the discharge consists entirely of flood flow (Pl. III, fig. 1), the floods which in the upper portion of the river are quick rising and short, becoming less violent and more extended as they travel down the river. A few miles above the forks there is usually some water flowing in the main Cimarron River, and also below the site directly north from Liberal some water flows at all times of the year. As this perennial flow apparently passes the proposed dam site in some of the underlying strata, only the flood flows are available for storage. No investigations have been made to determine the proportion of the discharge at Garrett which reaches the forks. It is not probable that more than 20,000 of the 35,000 acre-feet estimated mean annual discharge at Garrett would be delivered into the reservoir by the main Cimarron. There is no perennial flow in the north fork of the Cimarron, such run-off as occurs resulting from the heavier local rains. Similarly, the portion of the drainage area on the main river between Garrett and the forks is but slightly productive of run-off.

It is the popular and local opinion that the discharge of the Cimarron River is much larger than that shown by the previously mentioned actual measurements. Records available at present cover too short a period to be conclusive as to the available water supply, and future investigations might show a somewhat larger dependable run-off. However, on the basis of all present knowledge, the construction of a reservoir having a capacity larger than the 23,800 acre-feet surveyed could not be recommended. Should later studies show a larger amount of water to be available, it would be feasible to increase the capacity to any desired size.

Capacity of Cimarron Reservoir site.

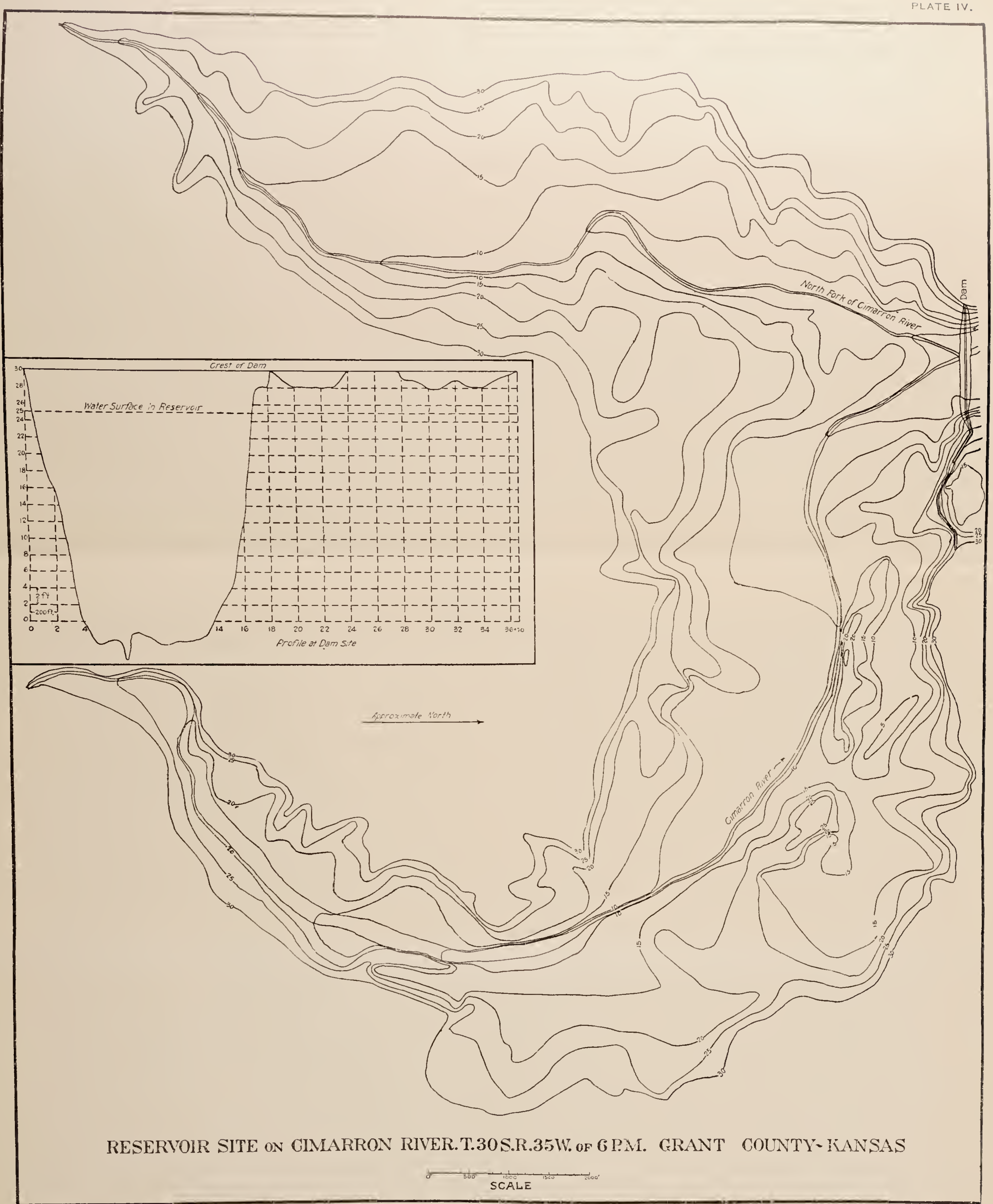
Contour.	Area.	Capacity of section.	Total capacity.
Feet	*Acres.*	*Acre-feet.*	*Acre-feet.*
0	126.9	....	....
5	207.9	587	587
10	610.7	2,046	2,633
15	1,133.2	4,360	6,993
20	1,681.6	7,037	14,030
25	2,208.5	9,725	23,755
30	2,538.6	11,868	35,623

The accompanying map (Pl. IV) shows the topography of this reservoir site. The main Cimarron turns northward for about a mile in its course to meet the north fork. On the south side of the main valley the bordering hills also extend northward toward the junction of the two branches, thus narrowing the general Cimarron Valley from an average width of 1 mile to about one-fourth of this distance and making the dam site for this reservoir. These hills are quite

FIG. 1.—CHANNEL OF CIMARRON RIVER AT FORKS, GRANT COUNTY, KANS.

FIG. 2.—DAM SITE ON CLEVELAND RUN, NEAR ST. FRANCIS, KANS.

(Note rough erosion of sides.)



RESERVOIR SITE ON CIMARRON RIVER, TOWNSHIP 30 SOUTH, RANGE 35 WEST, 6TH P. M., GRANT COUNTY, KANS.

rolling topographically, and have a typical sand-blown appearance. The main body of the dam would have a length of 1,700 feet; there would also be a continuation having a height of 5 to 10 feet extending 2,000 feet along the crest of the lower sand hills. With a top width of 20 feet and slopes of $2\frac{1}{2}$ to 1 on the inner side and 2 to 1 on the outer side, 143,000 cubic yards of earth fill would be required. This could be obtained from the higher areas at either end or from the inside of the dam. The hills at the north end would give the better character of material, the general soils being classified in a bulletin of the Bureau of Soils, United States Department of Agriculture,[1] as a sand and sandy loam.

Owing to the limited funds and short time available, no examination of subsurface conditions could be made. The river has cut and maintains a very regular canal-shaped channel, which for the first one-half mile below the forks has a grade of $5\frac{1}{2}$ feet per mile and a cross section of 25 to 30 feet in width and 6 to 8 feet in depth, the sides sloping about one-third to one. The silt deposited by the overflow has raised the banks of the stream slightly above the general level of the bottoms. The profile of the dam site shown with the map of the site (Pl. II) is a typical cross section of the bottom lands. The extent to which piling or other means of preventing seepage under the dam would be required can be determined only from careful examination and exploration. The sinking of the low flow a few miles above the dam site and its reappearance below make a thorough examination of this feature necessary before any definite plans can be made for the construction of storage here. In making the approximate estimate of cost sheet piling 25 feet deep for 2,000 feet in length was assumed to be necessary.

A spillway can be constructed near the south end of the dam, which will discharge into the river sufficiently far below the dam site. Protection, preferably a concrete paving, to prevent the overflow from washing the slopes of the sand hills would be required. For the outlet two concrete tubes 36 inches in diameter, with standard type of cast-iron gates, were used as a basis of estimate. A 4-inch concrete paving on the upper side was also included. The above-mentioned items, together with allowances for the purchase of the 2,200 acres to be flooded at $10 per acre, engineering at 10 per cent, and interest during construction and development for two years at 6 per cent, and other minor items, give a total estimated cost of $147,000, or $6.30 per acre-foot of capacity.

One and one-half acre-feet of water should be delivered at the farm, which would require the storage of $2\frac{1}{2}$ acre-feet in the reservoir, or the site as surveyed for a capacity of 23,800 acre-feet could supply 9,520 acres. This would give an estimated cost for storage only of $15.75 per acre.

No surveys for canal lines were made, and the length of ditch which would be required is unknown. Probably 20 to 30 miles would command all the upland for which a water supply is available. While no actual estimate of the cost of the main canal system can be made without some field examination, it is to be expected that it would be at least $10 to $20 per acre, which would give a total estimated construction cost of about $25 to $35 per acre. The lands to be served have a present value for dry farming of about $10 per acre.

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[1] Reconnoissance Soil Survey of Western Kansas. U. S. Dept. Agr., Bur. Soils, Advance Sheets—Field Operations of the Bureau of Soils, 1910, p. 49.

Without further knowledge of the water supply and of subsurface conditions at the reservoir and surveys for canal location, no definite conclusions can be drawn as to the feasibility of this project. Sufficient investigation has been made, however, to indicate the general conditions which must govern in any developments of the water supply of the Cimarron River. While the full course of the Cimarron was not visited in this reconnoissance, this site is considered by those locally in a position to judge to be the most favorable of any along the river, at least in Kansas. While the estimated cost, as indicated from the work during the past season, is not excessive, the general uncertainty regarding some of the important features of this project render doubtful any profits that might be expected from its construction. It would not be practicable to plan a development for more than 10,000 acres, and in some years the supply might be insufficient for this acreage.

SMALL RESERVOIR SITE ON CLEVELAND RUN NEAR ST. FRANCIS.

This small reservoir site, which is typical of the smoother and more rounded topography of many small creeks and washes, particularly in the northern portion of western Kansas, is situated about 8 miles from St. Francis on the north side of the South Fork of Republican River. The topography of the site is shown by the accompanying map (fig. 7). With a dam 20 feet high, storing a maximum depth of water of 17 feet, and having a length of 500 feet, a total capacity of 128 acre-feet could be secured, as shown on the accompanying table.

Capacity of reservoir site.

Contour.	Area.	Capacity of section.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
2	0.33	0.33	0.33
4	1.04	1.37	1.70
6	2.16	3.20	4.90
8	4.65	6.81	11.71
10	7.01	11.66	23.37
12	9.77	16.78	40.15
14	12.40	22.17	62.32
16	16.77	29.17	91.49
18	19.66	36.43	127.92

As in the case of other such sites whose drainage extends to the broad and flat uplands, the tributary area is indefinite in extent. While approximately 5 or 6 square miles, it is not closely determinable from any available maps. The discharge is torrential following the heavier rains. According to the opinion of those familiar with the stream, there is an average of about one flood flow per year—in some years none occurs, while in others there may be two or more. There is a well-eroded creek channel (Pl. III, fig. 1), the run-off at times being sufficient to overflow the flat bottoms. There are springs on the upper portion of the creek which are used for stock and domestic purposes, but they were producing but little flow at the reservoir site at the time of the survey. It is probable that in many years the local run-off would be sufficient to fill the reservoir, but in others the supply would be unreliable. This particular site has an advantage over others of which it was taken as an example in that a water supply

can be obtained from a ditch diverting water from the South Fork of Republican River, about 8 miles above.

Sufficient irrigable land is available immediately below the site to fully utilize all water stored. As this land is also a part of the valley

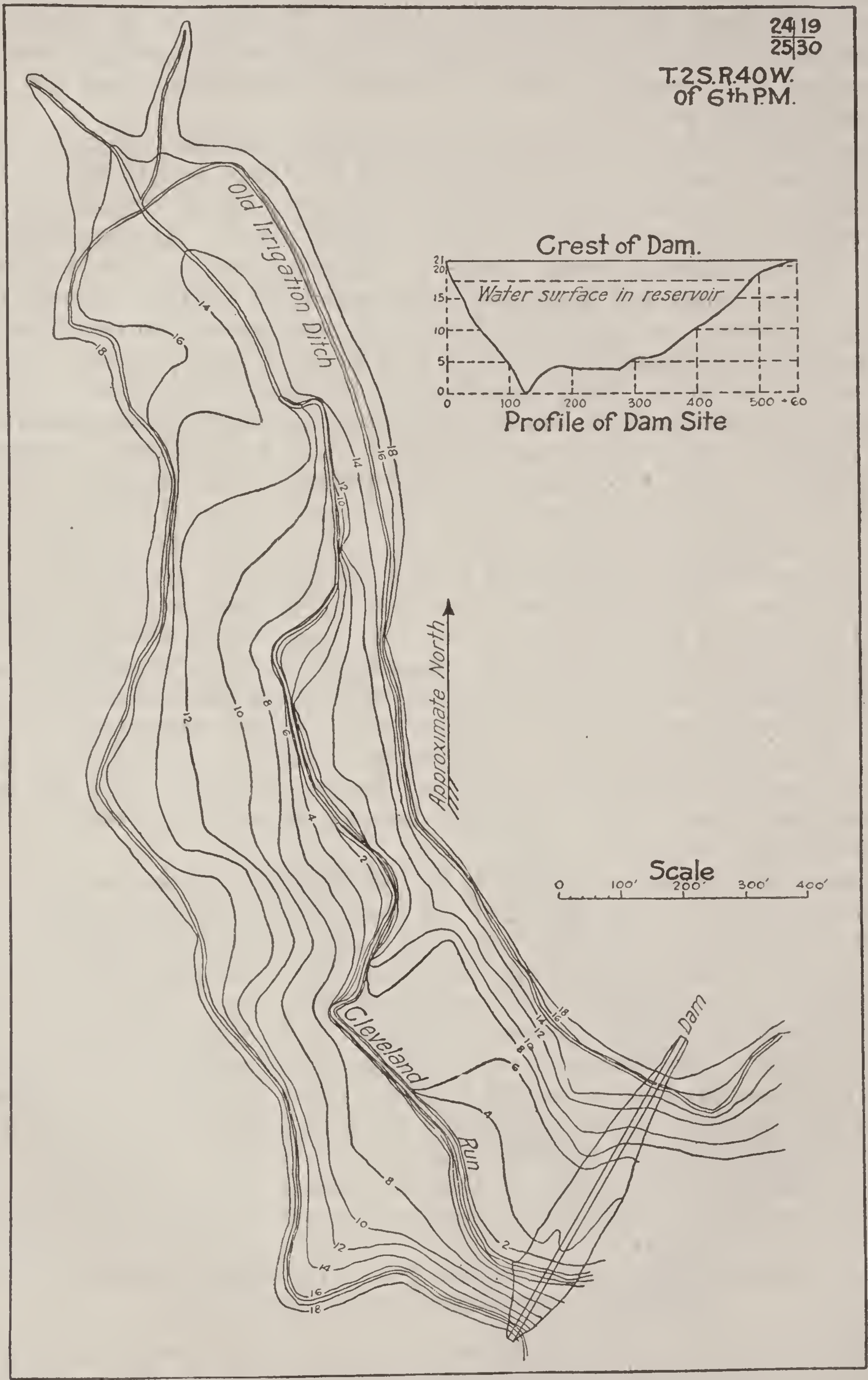

FIG. 7.—Cleveland Run reservoir site, Cheyenne County, Kans.

of the South Fork of Republican River, where the underground water lies largely within reach of the deeper plant roots, a higher duty may be feasible than in the average location. A general duty of 1½ acre-

feet per acre delivered at the land may be assumed. For such storage as will be constructed in units of this size the losses in canal transmission may be neglected as the ditch required will be of but little length. This duty would allow the reservoir to serve 85 acres. Where conditions permit, alfalfa is the preferred crop in this vicinity, usually yielding three crops per season. The lands at present in alfalfa are usually a part of a larger general ranch, making it hard to determine their separate value, although some of the best are held for nearly $100 per acre.

The conditions for construction are quite favorable. Except close to the creek channel the foundation of the dam would be on firm material, which would require only the removal of the organic matter and plowing of the surface to secure a good bond. At the creek but little extra material would need to be removed to uncover good earth. The usual soil is of good depth and the surface appearances do not indicate that any difficulties from seepage are to be expected. A carefully filled cut-off trench 3 feet deep should provide for this feature. The soil is that classified by the Soil Survey as a canyon loam, being intermediate between the sandy soils of the bottom lands and the silt loams of the uplands, and should therefore be suitable for making a tight embankment when properly put in place. Earth can be obtained from either end of the dam or from the inside of the site. A good location for a spillway is lacking, but one could be constructed around the north end of the dam with a maximum cut of about 7 feet. If the material from this cut is used as part of the fill for the dam the additional expense for the spillway would be small. No rock or gravel for slope paving was found in the vicinity, but sand can be obtained within a distance of 1 mile from the bed of the South Fork of Republican River. The cost of a concrete paving in a reservoir of this size would be excessive and some of the cheaper temporary forms of protection, such as brush or straw, may be more economically used. In using this cheaper material the wetted slope should be made 3 to 1.

A dam having side slopes of 2½ to 1 on the upper side and 2 to 1 on the lower, with a top width of 10 feet, would require 9,980 cubic yards of material and would have 1,800 square yards of surface on its upper side. Without paving, this dam has been estimated to cost about $2,400, or $18.80 per acre-foot of capacity. This cost would include the purchase of 20 acres of land to be flooded, a 12-inch outlet pipe and gate, and the spillway. Owing to the peculiar conditions of this particular site, it might be filled more than once each season by using the ditch from the South Fork of Republican River, thus reducing the cost per acre-foot of water available annually. Considered, however, as a typical site on a small stream depending entirely on local run-off, the utilization of this site would not be feasible.

SMALL RESERVOIR SITE IN SECTION 19, TOWNSHIP 2 SOUTH, RANGE 39 WEST, SIXTH PRINCIPAL MERIDIAN.

This small site, which is representative of the steeper and more roughly eroded small washes which are common in this portion of the State, is located about 9 miles north of St. Francis and about 1 mile from the site on Cleveland Run just described. While no rock outcrops, the sides of the site are steep and rough, as shown in the accompanying map (fig. 8). The fall of the draw on the reservoir

averages 2 per cent, or 100 feet per mile. With a dam 25 feet high, storing a maximum depth of water of 22 feet, and having a length of 500 feet, a total capacity of 82 acre-feet can be obtained.

Capacity of reservoir site in northwest ¼, section 19, township 2 south, range 39 west, sixth principal meridian.

Contour.	Area.	Capacity of section.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
2	0.60		
4	.36	0.42	0.42
6	.58	.94	1.36
8	1.30	1.88	3.24
10	2.17	3.47	6.71
12	2.83	5.00	11.71
14	3.68	6.51	18.22
16	4.62	8.30	26.52
18	5.62	10.24	36.76
20	6.67	12.29	49.05
22	8.34	15.01	64.06
24	10.06	18.40	82.46

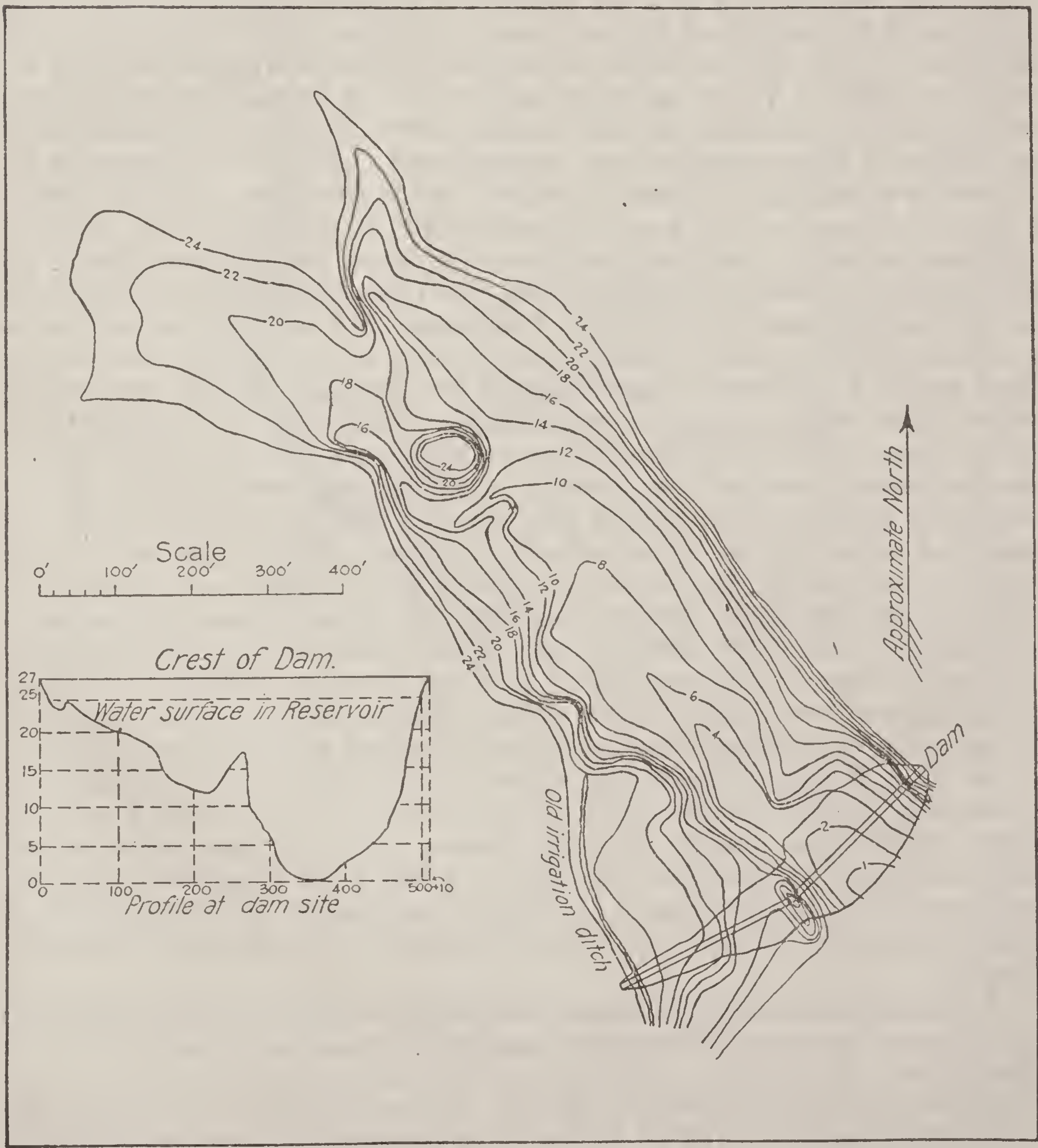

Fig. 8.—Reservoir site in northwest quarter, section 19, township 2 south, range 39 west 6th P. M.

The drainage area tributary to the site consists of 2 to 3 square miles of rolling slopes and flat uplands, the actual extent being indefinite. Torrential run-off follows heavy local rains. The floods, which last but a few hours, have not been of sufficient duration or size to erode any well-defined stream channel in the close sod of the bottom. The run-off available varies with the rainfall in the different years, and in some years of low precipitation may be insufficient to supply the capacity of the site. As in the case of the site on Cleveland Run, it would be possible to obtain water through the ditch at present constructed, which diverts water from the South Fork of the Republican River near St. Francis.

Sufficient irrigable land lies immediately below this site to fully utilize any water stored, and the short length of ditch required will reduce the losses in transmission to a minimum. On the basis of a duty of 1½ acre-feet per acre, 55 acres could be supplied. The character of the land and its value are similar to that under the Cleveland Run site, previously described.

The conditions for the construction of the dam are favorable. A dam with slopes of 2½ to 1 on the inner side and 2 to 1 on the outer side and a top width of 10 feet would require 13,900 cubic yards of material. This can be obtained with short hauls from either end or from the sides. While no examination of the subsurface conditions was made, the soils are usually uniform for considerable depth, and no difficulty from seepage is to be expected. It will be necessary to excavate a spillway around the north end of the dam. As the material can be used in the dam, the additional expense for the spillway will not be large. No rock or gravel for slope paving were found in the vicinity. Sand can be obtained from the bed of the South Fork of the Republican River within a distance of 1 mile. The cost of a concrete paving on the 2,125 square yards of the upper side of the dam would be excessive, and some of the cheaper though temporary substitutes might be more economical. Including the preparation of the dam foundation, the outlets, and the purchase of flood lands, the estimated cost without paving is $32.50 per acre-foot for the 82 acre-foot capacity, or $48.75 per acre for the land which could be supplied on a duty of 1½ acre-feet per acre. While the use of the present ditch might permit the reservoir in this particular case to be filled more than once during a season, and thus increase the acreage served and reduce the cost per acre, this would not be true generally of similar sites in this portion of western Kansas. While the slopes of such draws are higher in this vicinity, where the general topography is steeper and rougher, than in the more central and southern portions of western Kansas, this site is a good illustration of the difficulty of obtaining storage on the small, steeply-eroded draws which have not worn themselves deeply into the plains. As the dam sites which may be found in draws of this type are but little narrower than the reservoir sites behind them, the opportunities for obtaining storage where the slope of the creeks is as high as in this case are evidently limited.

A dam 14 feet high, storing a maximum depth of 11 feet, could be constructed so as to utilize a natural spillway site at station 2 of the dam shown on the map. This would give a capacity of only 15 acre-feet and, with a construction similar to that described for the larger one, would require a fall of 3,250 cubic yards and have an estimated cost, including flooded lands, etc., of $800 per acre-foot, which is too high for practical construction at present.

SMALL RESERVOIR NEAR THE MOUTH OF LADDER CREEK, LOGAN COUNTY, KANS.

This small reservoir site, which is typical of those on the moderate-sized creeks in the central part of western Kansas, is situated about

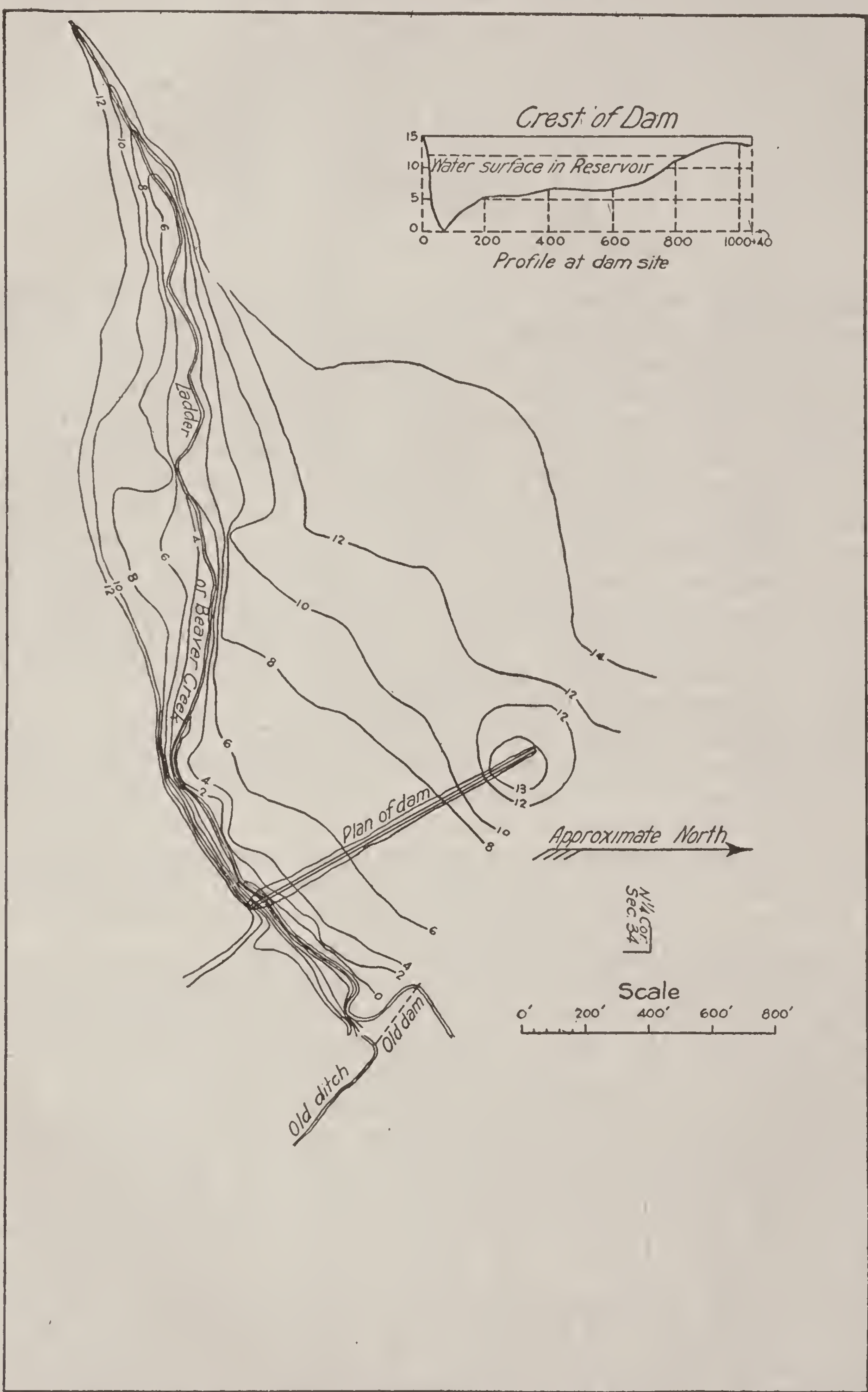

FIG. 9.—Ladder, or Beaver Creek, reservoir site, Logan County, Kans.

25 miles north of Scott City and about one-fourth mile above the junction of Ladder Creek with Smoky Hill River. The topography of the site is shown in figure 9. With a dam 15 feet high, storing a maxi-

mum depth of water of 12 feet and having a length of 960 feet, a total capacity of 140 acre-feet could be secured.

Capacity of Ladder Creek reservoir site.

Contour.	Area.	Capacity of section.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
2	0.50	....	....
4	2.50	3.00	3.00
6	7.60	10.10	13.10
8	16.80	24.40	37.50
10	25.60	42.40	79.90
12	35.90	61.50	141.40

Ladder Creek, or Beaver Creek as it is called locally, rises in eastern Colorado. Like the other Kansas streams in this part of the State, the extent of its drainage area is indefinite, but is probably between 1,200 and 1,500 square miles. Much of this area is practically non-productive, consisting of depressions or "lagoons" which collect any run-off there may be in their vicinity, and of broad sod-covered flats which retain practically all of the precipitation except in the larger storms. There are evidences of floods which have left the creek banks at the reservoir site. No estimate of their size can be made, however, with any degree of accuracy. While, owing to the length of the drainage area, flood waters from the upper portions would be less sharp and more extended by the time the reservoir site was reached, ample spillway facilities should be provided, as the capacity of the reservoir is small in proportion to the total discharge.

Ladder Creek is one of the few western Kansas streams which has a perennial flow. This flow is supplied by springs which are at present used to some extent for irrigation. At the time of this survey the creek was flowing about 3 second-feet at the dam site, and those familiar with the stream state that this flow is maintained throughout the year. No storage development is needed until this normal flow is fully utilized. Whenever desired the water supply not usable directly will be ample for filling the reservoir as surveyed.

The full utilization of this stream would require the carrying of some of the supply across to the north side of the Smoky Hill River. There are about 100 acres in the bottoms on the south side immediately below the site. Beyond this the bluffs approach the river for some distance. The lands lying on the north side could be reached by a flume or siphon or by allowing the water to continue to flow into the Smoky Hill River and diverting it directly, although the latter method might involve some loss in the sandy bed of the river. There is more than sufficient bottom land on the north side to utilize the available water supply. The bottom soils are sandier than those generally found in this portion of the State and a duty of 2½ acre-feet of stored water should be allowed to cover transmission losses and crop requirements. On this basis 56 acres could be supplied from this reservoir. Owing to the distance (25 miles) from a railroad, land values are not high. Much of the uplands are now used for grazing and the irrigated land could be used to advantage for the raising of

winter feed. Some land is now cultivated—Kafir corn, milo maize, and sorghum being raised.

A more careful preparation of the dam foundation should be made here than in the other two small sites surveyed, owing to the more open and sandy character of the soils. More compact material can be obtained from the hill at the south end of the dam site and the use of this for part of the embankment throughout its full length is recommended. A deeper cut-off trench is also included in the estimate. With a top width of 8 feet and slopes of 2½ to 1 on the inner side and 2 to 1 on the outer side, 8,100 cubic yards of material would be required, the area of the upper side of the dam being 2,180 square yards. There is a natural spillway site at the planned elevation of high water near the north end of the dam. No cost for the protection of this is included in the estimate as while the soil is too sandy to resist much erosion, in case of serious cutting protective measures can be provided as needed. Including the purchase of 36 acres of land to be flooded, and the preparation of the foundation and the construction of outlet, the estimated cost, without paving the upper side of the dam, is $3,000 or $21.50 per acre-foot for 140 acre-feet capacity. Allowing a duty of 2½ acre-feet per acre, gives an estimated cost of $53.75 per acre. Owing to the large area of surface of the dam exposed to the water in proportion to the capacity, the cost of a concrete paving would be excessive. Some soft rock is available near the dam site which might be used for this purpose.

The local value of an irrigation water supply has been low in this vicinity as is shown by the fact that the dependable perennial flow of the creek is as yet but slightly utilized and the cost of this storage would be greater than its present value. This site can be taken, however, as typical topographically of such sites in this portion of the State, some of which might be found nearer to transportation facilities and markets so that the water supply would have a higher value.

Utilization of Underground Waters by Pumping Near Garden City, Kans.

The utilization of underground waters by pumping is an important factor in the irrigation development of western Kansas. The greatest development of this kind at the present time is in the Arkansas Valley in Finney and Kearny Counties. The accompanying map (fig. 10) shows the area irrigated by pumping from wells in the territory between Garden City and Lakin, a distance of 23 miles. Aside from 3,000 acres irrigated by the United States Sugar & Land Co. from its central power station described elsewhere in this report, there were 55 individual pumping plants operating in this area in 1912, supplying water to 6,000 acres and capable of serving about 8,500 acres.

There are two general types of pumping plants in use, depending on whether water is pumped from shallow or deep wells. In the bottom or valley lands the depth to water ranges from 10 to 20 feet. Most of the shallow wells now bored are 16 inches in diameter and

range from 35 to 50 feet in depth. It has been found that from 250 to 400 gallons per minute can generally be obtained from one well. Where a larger flow is desired a group of wells is sunk and a centrifugal pump is connected to the wells by means of suction pipe graduated to decrease friction loss.

The deep-well plants are found on the uplands or plains and have been installed within the past two years. The success that has been attained in these plants has caused widespread interest throughout the western part of Kansas. The wells on the uplands are from 300 to 400 feet in depth, depending upon the soil formation and water strata encountered. The wells proper are 24 inches in diameter to

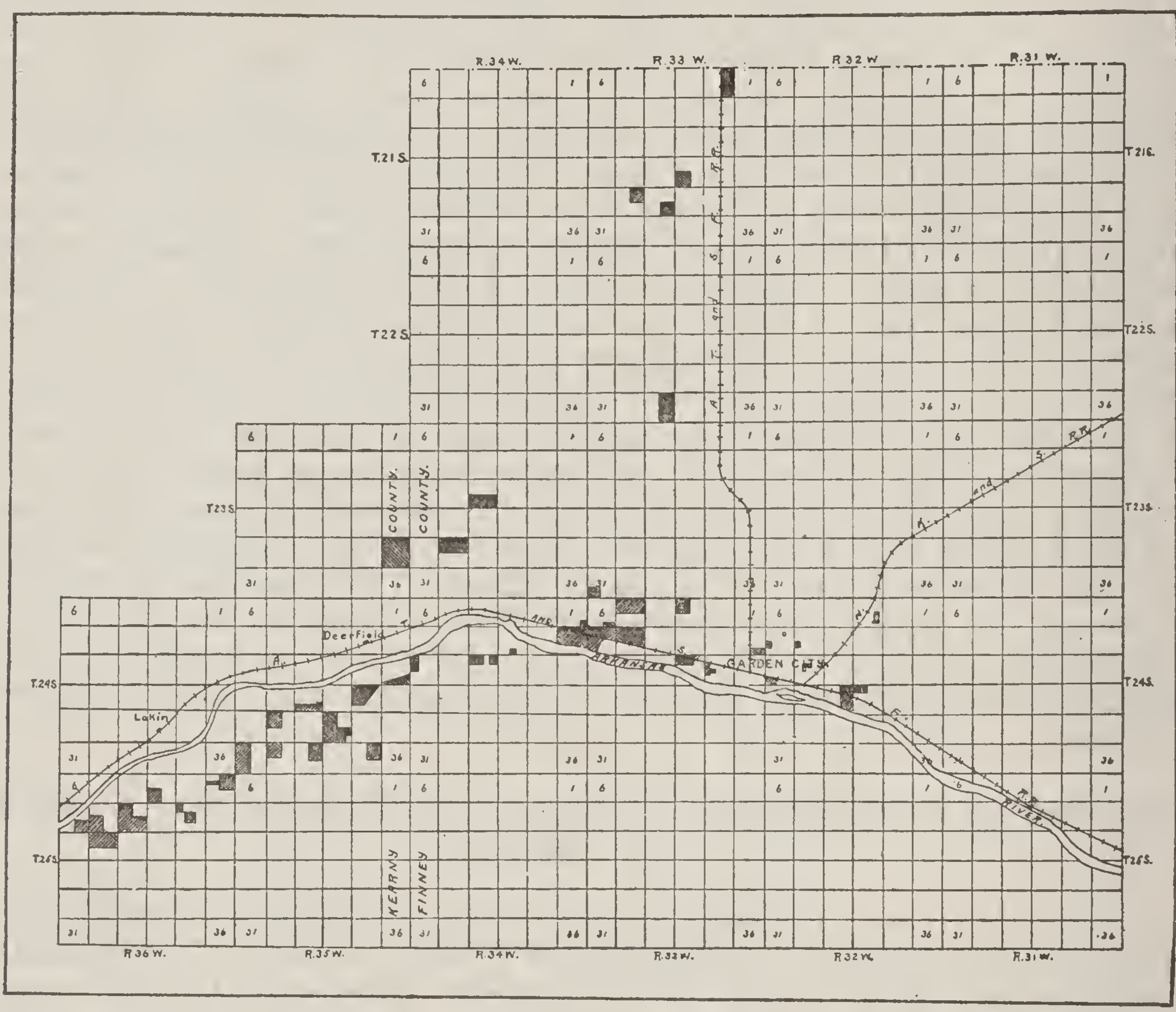

FIG. 10.—Area irrigated by pumping in portion of Arkansas Valley in western Kansas.

a point where a turbine or multiple stage centrifugal pump is set, below which a smaller diameter of casing is used. For deep wells a No. 6 or 8 gauge steel casing is generally used and this is perforated and wrapped with steel wire having a trapezoidal cross section. The average lift on the uplands is about 125 feet, and in some cases water is being raised over 150 feet.

The internal-combustion engine of either the two or four cycle type using distillate or crude oil for fuel is used almost exclusively for power. Distillate is now obtained at Garden City for 3 to 4 cents per gallon. This cheap fuel makes it possible to pump for higher lifts than would otherwise be practicable.

The pumping plant which was installed in 1911 by this office under cooperative agreement with the Kansas Experiment Station, Garden City Commercial Club, and Finney County Commissioners on the experiment farm at Garden City is typical of the deep-well plants now being installed on the uplands in western Kansas, a complete description of which follows. (Pl. V.)

Equipment.

Engine, 75 horsepower, 190 revolutions per minute, 8-inch pulley; fuel, oil; fuel consumption, full load, 1.15 pints per horsepower hour.

Pump, No. 6, two-stage vertical centrifugal, $9\frac{5}{8}$-inch discharge, $8\frac{1}{4}$-inch suction, 16-inch pulley; pump set 120 feet; 40 feet of suction pipe.

Well, 24 inches diameter, 180 feet deep; 90 feet blank pit; 90 feet of wire-wound strainer.

Belt, 14-inch double leather, 30 feet centers.

Cost.

Engine, set on foundation furnished by purchasers		$1,705.00
Pump, complete, set		764.28
Well:		
Drilling hole and setting pit and strainer	$1,136.25	
90 feet of 24-inch strainer, at $10	900.00	
90 feet of 24-inch steel pipe, at $3.50	315.00	
Hauling	39.25	
Fuel	157.04	
Board of well company's men	113.41	
Lumber, derrick	72.07	
		2,733.02
Belt		152.05
House, complete		446.02
Tank:		
Storage, 10,000 gallons, complete, set		201.75
Wagon, 600 gallons, complete with frame		48.25
Foundation		82.40
Weir		22.60
Labor, installing engine		48.95
Paint and painting derrick		19.80
Total cost as finished, December 1, 1911		6,224.12

Performance.

Quantity of water pumped per minute (average) 765 gallons with average lift of 135 feet equals 1.7 cubic feet per second, or 1.41 acre-feet per 10 hours.

Cost.

Fuel, $0.0375 per gallon. Lubricating oil, $0.30 per gallon. Total cost of fuel and lubricating oil per acre-foot of water, $2.48.

This plant, while in operation only one year, has given entire satisfaction, and there seems to be no diminution of the water supply. The log of this well shows 47 feet of loam soil and clay, 43 feet of gypsum and stone, and 90 feet of water-bearing sand and gravel. The plant was used to irrigate 50 acres of experimental crops in 1912, consisting of alfalfa, sugar beets, sorghums, melons, etc. It is thought that with a careful use of water this plant should be capable of serving 160 acres of land. The cost of the deep-well plants varies almost directly with the total lift. With an average lift of 125 feet the cost for a complete plant with a capacity of 1,000 gallons per

minute is about $50 per foot of lift or $6,250. On the basis of a plant of this capacity serving 160 acres of land, the cost per acre is $39. The average cost of the plants pumping from the shallow wells in the bottom lands having a capacity of 2,000 gallons per minute is about $3,200 or $20 per acre on the basis of a plant serving 160 acres.

There are numerous smaller plants having a capacity of about 1,000 gallons per minute. With these plants a small earth reservoir is provided as shown in Plate VI. This plant, belonging to George Vincent, of Garden City, consists of a 15-horsepower gasoline engine, belt connected to a No. 6 horizontal centrifugal pump having a capacity of 1,200 gallons per minute with a lift of 12 feet. Water is obtained from one 16-inch well 46 feet deep and discharged into an earth reservoir 75 feet square and 6 feet deep, giving a capacity of 0.77 acre-foot. The total cost of this plant was $1,000, and 40 acres of alfalfa were irrigated in 1912. Accurate data on the duty of water in this section are not available, but it is the general opinion among irrigators that the average use of water on the bottom lands amounts to about 4 acre-feet per acre per season. The following table taken from a paper read before the Kansas irrigation convention at Garden City in 1912 by L. M. Williams presents some interesting figures as to the comparative cost of the shallow-well and deep-well type of plants in the vicinity of Garden City. The aggregate cost of irrigation is segregated into unit costs per acre-foot, and the figures are based on operating 150 days per year 12 hours per day.

Table showing comparative cost of irrigation from shallow-well and deep-well types of pumping plants.

	Shallow-well type.	Deep-well type.
Capacity in gallons per minute	2,000	1,000
Average lift in feet	30	125
Average horsepower required	30	75
Number of men per day	1	1
Labor cost per day	$2.00	$2.00
Number of acre-feet pumped per day	4.4	2.2
Gallons of fuel consumed per day	45	112.5
Fuel cost per day at 3 cents per gallon	$1.33	$3.35
Lubricating oil used per day, gallons	1	2.7
Lubricating oil; cost per day at 30 cents per gallon	$0.30	$0.80
Estimated cost of plant	$3,200.00	$6,250.00
Interest on investment at 7 per cent	$224.00	$435.50
Depreciation at 8 per cent	$256.00	$500.00
Total annual cost of interest and depreciation	$480.00	$935.50
Interest and depreciation, cost per operating day	$3.20	$6.25
Total cost of operating per day	$6.85	$12.40
Total acre-feet of water pumped	660	330
Cost per acre per season	$1.56	$5.75
Fuel and lubricating oil, cost per acre-foot	$0.375	$1.90
Labor cost per acre-foot	$0.455	$0.91
Interest and depreciation, cost per acre-foot	$0.73	$2.84

Assuming a duty of 4 acre-feet per acre on the bottom lands and 2 acre-feet per acre on the uplands, the total cost per acre per season on the figures presented would be $6.24 on the bottom lands and $11.50 on the uplands.

A private company has several successful pumping plants in operation, one plant consisting of a 150-horsepower engine burning crude oil connected to a multistage turbine pump, which irrigated 320

PUMPING PLANT, IRRIGATION EXPERIMENT STATION, GARDEN CITY, KANS.

PUMPING PLANT WITH EARTH RESERVOIR, GARDEN CITY, KANS.

WINDMILL AND SMALL CONCRETE RESERVOIR, SYRACUSE, KANS.

WINDMILL AND EARTH RESERVOIR NEAR GARDEN CITY, KANS.

acres of beets in 1912. The average yield was 15 tons per acre, which sold for \$5.50 per ton at the sugar factory. While this yield is above the present average in the sugar-beet district, it should be generally attained with a careful use of water and proper methods of farming. The average cost of raising sugar beets is given by the company as \$30 per acre, to which must be added the cost of irrigation, estimated at \$11.50 per acre on the uplands. While pumping on the uplands is still in the experimental stage, with cheap fuel encouragement is offered to the farmer of western Kansas where a gravity supply is not available.

The company which owns and operates the beet-sugar factory at Garden City has a central power station at Deerfield for pumping water for irrigating sugar beets. Much of the water is used as a supplementary supply to that received from the company's canals. A producer gas plant in which crude oil is used for fuel is operated. The equipment consists of a double tandem 400-horsepower engine direct connected to a 250-kilowatt generator. There is also an auxiliary plant consisting of a 90-horsepower gas engine which may be used when repairs are being made to the other engine. Power is distributed to 14 pumping stations over 20 miles of transmission line. Each pumping station is equipped with a 30-horsepower electric motor, belt connected to a No. 8 horizontal centrifugal pump. At each station water is pumped from a group of 5 wells which are 16 inches in diameter and average 40 feet in depth. The average depth to water is 13 feet and the average total pumping head is 28 feet. During the season of 1911 this plant was operated 3,767 hours, at a total cost of \$13,907.40. The water pumped amounted to 9,201 acre-feet, which was applied to 3,060 acres of land, or 3 feet in depth over each acre. The cost per acre-foot of water pumped amounted to \$1.51 and the cost per acre of land irrigated was \$4.54, which does not include interest and depreciation.

Use of Windmills in Irrigation.

Where the cost of installing a fuel pumping plant is deemed too expensive attention should be given to the windmill with the small reservoir, the importance of which can not be overestimated. Nearly every farm in western Kansas and western Oklahoma has a windmill used for stock and domestic purposes, and by building a small earth or concrete reservoir sufficient water can be stored for irrigating the garden and family orchard or small tracts of 2 to 5 acres. (Pls. VII and VIII.) One case is recorded in Scott County of 60 acres being irrigated by means of 10 windmills and a single reservoir. Even the use of a small water supply makes possible the growth of a few trees and flowers, provides vegetables for the table, and adds attractiveness to many a home on the plains that otherwise might have been abandoned. The history of western Kansas would have been far different had the early settlers taken some means of providing for their domestic needs by irrigating only a small part of their homesteads.

The use of windmills in irrigation in the semiarid West has been described in a bulletin of the United States Department of Agriculture[1]

[1] U. S. Dept. Agr., Farmers' Bul. 394.

in which the methods of building reservoirs and installing windmills are given in detail. Attention is called to the size and shape of reservoirs, of which the circular reservoir is the most economical.

The following table gives the dimensions of circular reservoirs of different capacities; the quantities of earth in the embankments, if these have inside slopes of 3 to 1 and outside slopes of 1 to 1; the areas which can be irrigated, provided the reservoir full of water is used once in 10 days throughout 5 months and the land receives water to a depth of 1 foot; the size of mills recommended; and the costs of reservoirs and mills. The lift assumed in choosing the mills is 14 feet, which is about the average lift around Garden City.

Sizes of circular reservoirs and estimated cost for various areas of land to be irrigated.

Gross capacity of reservoir.	Depth of reservoir.	Diameter at bottom of embankment.	Diameter at top of embankment.	Bottom width of embankment.	Top width of embankment.	Amount of fill required.	Number and size of mills recommended.	Estimated cost of reservoir.	Estimated cost of plant erected and completed.[1]	Area irrigated.
Acre-feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Cu. yds.*				*Acres.*
0.07	4	21.30	45.30	19	3	212.00	1 8-foot..	$21.20	$81	1
.16	4	34.96	58.96	19	3	281.52	1 8-foot..	28.15	88	2
.24	4	45.62	69.62	19	3	336.25	1 10-foot.	33.62	113	3
.32	4	54.61	78.61	19	3	381.88	1 10-foot.	38.18	119	4
.40	4	62.27	86.27	19	3	422.46	1 12-foot.	42.24	202	5
.49	5	58.58	88.58	24	4	684.71	2 10-foot.	68.47	228	6
.56	5	63.64	93.64	24	4	725.80	2 12-foot.	72.58	392	7
.63	5	69.00	99.00	24	4	747.75	3 12-foot.	74.77	550	8
.72	5	74.37	104.37	24	4	813.51	3 12-foot.	81.35	561	9
.80	5	79.36	109.36	24	4	854.16	3 12-foot.	85.41	565	10

[1] Not including well.

In the following table is presented some condensed data of windmill irrigation around Garden City, Kans. The area irrigated, value and kinds of crops grown, size and cost of plant are given for 37 plants:

Condensed data of windmill irrigation.

GARDEN CITY, KANS.

Number of plant.	Area.	Crops.[1]	Number of trees.	Size of mill.	Cost of plant.	Size of reservoir.	Cost of reservoir.	Annual maintenance.	Value of crops.
	Acres.			*Feet.*		*Feet.*			
1	4.0	G and C	100	10; 12	$200	100 by 30 by 2	$20	$4.00	$300
2	20.0	G; SB; A	400	25; 10; 10	1,000	100 by 200 by 4	150	2.50	1,500
3	6.0	G; F; SB	700	12	200	75 by 100 by 5	20	.50	1,200
4	4.0	A and SB		12	200	75 by 100 by 5	20	.50	250
5	25.0	A	800	[2]3–12	360	90 by 185 by 3.5	100	30.00	1,600
6	8.0	A		12	120	150 by 60 by 3	50	10.00	350
7	8.0	G; SP; C		12	150	100 by 3, round	45	3.65	800
8	2.5	G	100	8	55	30 by 100 by 3	10	4.00	125
9	4.0	G; F; Fl	300	8; 10	85	30 by 35 by 3.5	15	2.00	200
10	3.0	G	100	10	102	20 by 70 by 2	15	1.50	500
11	2.0	G; F	40	10	75	30 by 50 by 2	12		150
12	8.0	G; F	800	8; 12	185	85 by 110 by 3	40	11.00	550
13	5.0	B; F; G	125	10	100	50 by 100 by 2.5	20	2.00	500
14	1.5	B; F; G	200	8	92	24 by 24 by 2	10	.75	400
15	2.5	G	100	8; 10	70	30 by 30 by 3	10		300
16	2.0	G and F	800	14	175	75 by 75 by 3.5	25	5.00	
17	7.0	G and SB	150	2–12	230	125 by 125 by 3	40	30.00	200
18	2.0	G	146	8	70	40 by 40 by 2.5	15	.50	150
19	1.0	G	200	8	12	35 by 35 by 2	10	3.00	200
20	5.0	B; F; G	800	2–8	150	50 by 50 by 2.5	50	1.50	300
21	4.0	G and F	3,000	12	103	75 by 75 by 2.5	15	.50	500
22	4.0	SP		10	93	30 by 70 by 3	15	.50	250
23	.25	C	30	8	62	50 by 50 by 3	25	.50	100
24	3.0	G and F	300	10	91	25 by 25 by 2	10	1.50	500
25	10.0	G; A; F	1,000	10; 12	230	100 by 110 by 3	30	1.50	750
26	3.0	B; F; G	260	8; 8	90	30 by 50 by 3	13	1.35	500
27	4.0	G and F	375	12	128	50 by 30 by 3	12	15.00	500
28	12.0	G and F	500	2–12	225	100 by 500 by 3	50		500
29	10.0	G and F	150	2–12	193	75 by 100 by 2.5	15		1,500
30	5.0	B; F; G	100	12	72	60 by 60 by 4	20	5.00	200
31	2.5	B; F; G	100	2–8	164	40 by 50 by 2	10	.75	200
32	2.5	B; F; G	75	8	60	60 by 60 by 3	20	5.00	200
33	4.0	G		12	85	2.5 by 50 diam	40	7.00	200
34	4.0	G	300	12; 8; 8	250	100 by 100 by 3	50	12.00	300
35	2.0	G	800	8	75	20 by 25 by 2	10	None.	100
36	10.0	T	2,000	2–12	200	250 by 100 by 3	75		700
37	2.5	G	150	10	75	20 by 111 by 2.5	10	5.00	175

[1] The following abbreviations are used: A, alfalfa; B, berries; C, cantaloups; F, fruit; Fl, flowers; G, garden; SB, sugar beets; SP, sweet potatoes; St, strawberries; T, trees.
[2] This indicates three 12-foot mills. Other similar figures indicate number of mills of the size given.

Conclusions.

While, as explained in the introduction, neither time nor funds were available for a thorough investigation of the storage possibilities of western Kansas and Oklahoma, even by limiting the area covered to two or three western tiers of counties, such opportunities as were found for irrigation development by storage are not promising, and considered in relation to the total agricultural area the total acreage which can be supplied with water will never be more than a very small percentage of the available land. As in other semiarid regions where it is possible to maintain a home by an extensive system of dry farming, water for irrigation must be obtainable at a low cost, or its use will be long delayed, even though the advantages of irrigation over dry farming can be clearly demonstrated. When the water supply for irrigation is also generally both difficult to obtain and expensive, as in western Kansas and Oklahoma, its use will be still further delayed.

The typical surface formation of this area is a thick, overlying earth through which the stream erosion has not generally penetrated, such underlying shales as have been exposed being soft and eroding in generally easy slopes. It is this uniformity in the hard-

ness of the material eroded which prevents the formation of good reservoir sites, as they are considered, in the more mountainous regions. The valleys of the streams are in many cases of considerable breadth and of light slope in the direction of the stream, but owing to the uniform width of the valley erosion no economical dam site can be secured. The general irregularity and torrential character of the flow of the streams make it practically necessary to store directly on the stream beds, as any inlet canals to reservoirs apart from the streams would need to have very large carrying capacity in order to obtain the larger portion of the run-off. With large and reasonably certain water supplies available, dams across the wide valleys might be built of sufficient height so that the large capacity secured would reduce the unit cost within practicable limits. With the small and uncertain supplies that are found on all but one or two of the streams, such development of sites can not be considered practical, and the unit cost for sizes which can be regularly filled is more than the present demand for irrigation will warrant.

Irrigation development in this area has not been sufficiently extensive or permanently established for the value of water rights to become fixed, excepting in the Arkansas Valley. High-land pumping plants, although as yet at least partially experimental, are being installed in the Arkansas Valley, in which the annual cost of water will be in excess of $10 per acre. In order for such pumping to be profitable, the best agricultural use must be made of the land. As western Kansas and Oklahoma approach the limit of their development under dry farming and stock raising, it is to be expected that the interest and demand for irrigation will increase and that the cost which can be borne will also increase, although neither the present nor the future limit of cost can be satisfactorily determined. The estimated cost of the two larger projects surveyed in this investigation—those on Beaver Creek and Cimarron River—should be sufficiently low to leave some margin of profit to a promoting company. However, when the uncertainty of water supply, dam foundations, etc., are taken into consideration the margin is hardly sufficient to make the risk financially inviting.

The three smaller sites were selected as illustrative of the topographic conditions for storage on the smaller channels, their size being such as comes within the limit of the individual farmer. In such cases a somewhat higher unit cost can be borne, as a more intensive use of the water is probable than on the larger projects, and the marketing conditions for the products of small isolated irrigated tracts in a general dry-farming section are much more favorable. As the normal flow of the neighboring streams which can be obtained much more cheaply than a supply from these particular small storage sites has not as yet been fully utilized, their cost can hardly be considered as within the present economic limit, although eventually their use may be feasible. The greatest number of opportunities for storage in western Kansas and Oklahoma are of the size and character of these small sites, and careful investigation might disclose many of them, some of which might be developed at less cost than those selected for survey, although the average water supply would probably be less certain and reliable.

The following quotation summarizes the results of the investigations of reservoir sites by the United States Reclamation Service in Oklahoma, which covered a much larger area than the two counties included in this report, and which warranted statements regarding the character of the water supplies even more favorable than they would be if limited to the two counties included in the present examination.

The western part of Oklahoma is a region of uncertain rainfall. During ordinary years the precipitation, if properly distributed, would be ample for excellent crops. In some years it is properly distributed, while in others the crops are lost for lack of rain at the time when it is needed.

Recognizing that such a region needs irrigation, if it can be had at a reasonable cost, extensive reconnoissance surveys have been made on all the streams in this semiarid region during several past seasons, and stream measurements for determining the available water supply have been pushed rapidly since April, 1905.

Surveys and examinations have been made of every possible site for an irrigation project on Cimarron and Canadian Rivers, Beaver Creek, Wolf Creek, Washita River, and Red River and their tributaries. With the exception of the main Cimarron River above Garrett, the North Fork of Red River at points near Snyder and Lugert, and Otter Creek near Mountain Park, these streams may be generally described as occupying sandy valleys of practically uniform slope and width, with no narrow places where dams can be economically constructed of stone or earth, as there is no bedrock for base and abutments of dams and no suitable rock for masonry or concrete.

All of the streams are very irregular in flow, being practically dry at certain seasons, deficient in volume ordinarily, and subject to violent floods of short duration at irregular intervals. Such streams can not be utilized for irrigation on a large scale without ample storage, and the conditions for storage do not exist, except at the points mentioned. The largest and best site that has been found is on the North Fork of Red River in Greer and Kiowa Counties, near the towns of Headrick and Snyder, and is known as the Navajo reservoir site. Extensive surveys and estimates have been made there to determine the feasibility of an irrigation project.[1]

There is another class of irrigation development which is the most promising for this area in general. This is the small windmill or other pumping plant with storage reservoir or the small reservoir to store sufficient storm run-off to supply the garden products and trees which can add so largely to the comfort and pleasure of farm life in semiarid sections of extensive farming. The acreage of such units is so small that the value per acre of the crops is misleading, as is also the cost per acre of the water supply. As the garden products are intended for home consumption, their value is not easily measured in dollars, although they will effect a considerable annual saving to the farmer in store bills. In the area covered in this investigation there are probably but few large farms on which a windmill and small reservoir can not be made to irrigate a half acre to an acre at a cost well within its value. Attempts to irrigate more than enough crops for the home consumption have not been generally successful on large farms devoted to dry-farm crops, as the equipment and methods, as well as the temperament of the farmers, are widely different in extensive cultivation and in irrigated truck raising. It is in utilizing the small supplies on individual farms, either of storm run-off or by pumping, that the greatest benefit is most likely to be realized from irrigation in western Kansas and Oklahoma.

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[1] Ann. Rpt. U. S. Reclamation Service, 5 (1906), p. 244.

While this reconnoissance for storage may be lacking in some details it is doubtful if a more thorough search for reservoir sites would add sufficient information to justify its expense or that sites would be found whose development would be undertaken either by Federal agencies or by private parties, at least under present conditions. The most significant new development now taking place is the pumping from the underground water on the uplands, with lifts of over 100 feet. The best type of engine and fuel and the best pump head, as well as other details, are still matters of experiment. If it be proven feasible to draw from this underground supply at such high lifts the quantity of water which can be withdrawn without lowering the ground water level, and the depths and lifts required, will become matters of great importnace to this section. This is a subject falling more within the proper province of Federal investigation than a search for reservoir sites in this area. Each stream can be investigated independently for reservoir sites at an expense within the reach of those likely to utilize any opportunities which may be found. The whole ground water supply is more or less closely related in various locations and the expense of any general investigation would be beyond the means of individuals who were considering its use. Some general geological investigations have already been made by the United States Geological Survey. The source and quantity of the underground supply are questions whose solution will be very difficult, and any definite determination can not be made. However, a careful study in the light of additional information made available by the recent developments should add much to the present knowledge.

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